THE PRACTICAL OPTICIAN'S GUIDE.

H. L. TAYLOR

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THE PRACTICAL

OPTICIAN'S GUIDE.

AN ELEMENTARY COURSE FOR OPTICIANS.

BY

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PREFACE.

IN writing the present book my object has been to fit in necessary information between two limits. The one, a certain vague rule-of-thumb method practised still by probably the majority of opticians; the other, the minimum knowledge required by the careful operator.

Several matters are therefore discussed at greater length than under other circumstances would be, advisable, notably the comparison between the Dioptric system and the methods of measuring lenses used by the unskilled optician.

I have endeavoured to explain everything in language as simple as possible, and with this view have not hesitated to adopt suggestions and transpose ideas from the works of many authorities.

December, 1896.

H. L. T.

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CHAPTER I.

Refraction of Light.

1. Rays of Light. Light travels in straight lines, were it not so we should be able to see round a corner. For the convenience of description we speak of a *ray of light* meaning a very small line or streak. The grouping of a number of rays together forms a pencil or beam, such as is seen when bright sunlight streams through a small hole in a dark room.

2. Refraction of a Ray. The whole science of Optics is founded on the peculiar bending or deflection which light undergoes in passing from one medium to another of different density. As shown in the following illustration, unless the ray strike the surface between the two media *obliquely* no refraction takes place.

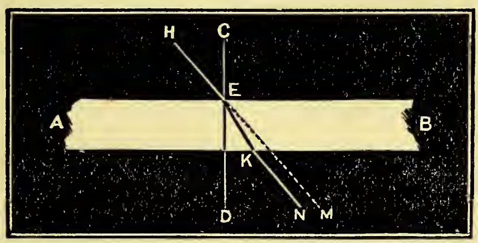


Fig. 1.

A B is a section of a sheet of glass, and C D a line drawn perpendicular to the surface. A ray of light passing along C D would undergo no refraction.

But suppose a ray of light from point H falls on the glass at E, that is obliquely, part of this ray will be reflected from the surface of the glass and part will pass through and emerge from the opposite side.

We must notice the latter part a little more particularly. In passing through the glass the ray is bent, and when it emerges on the other side is nearer the perpendicular C D than if it had continued in a straight line.

The ray is again bent on leaving the glass at K, but this time away from the perpendicular C D, so that generally speaking, a ray of light passing from a medium such as air into a denser one such as water, is refracted towards the perpendicular, but in passing from a dense medium into a rarer one it is refracted away from the perpendicular. We see from the illustration that had the ray of light not been refracted it would have passed on in the direction H M.

Conversely, light from N, meeting the glass at K, would pass through and emerge at E, in the direction E H, but if the eye were placed at H the light would appear to come from M instead of N.

This may be tested by holding a piece of plate-glass aslant before the eye and viewing an object through it, we notice a displacement in the position of N corresponding to the distance between N and M.

Although the ray in the illustration is twice bent or refracted, yet on finally leaving the glass it is parallel to the direction in which it entered. This is because the sides of the glass are parallel, in any other case the emergent ray would have taken a course dependent entirely upon the inclination of the sides to each other.

Many familiar phenomena may be explained by refraction. A stick immersed obliquely in water appears

bent from the point where it touches the surface, and looking into a well or pond we always imagine that the bottom is raised, the water seeming shallower than it really is.

We have, so far, dealt only with rays of light traversing a sheet of glass with parallel sides, and now turn our attention to the refraction of rays passing through transparent bodies whose sides are not parallel.

3. The Prism. An optical prism may be described as a wedge of transparent material having two plane faces inclined to each other, thus forming an angle between them.

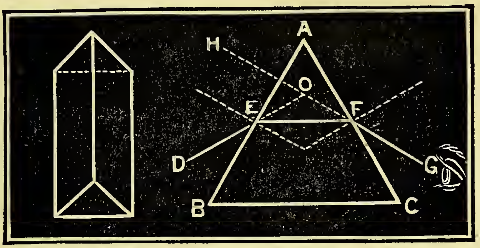


Fig. 2.

The above is an illustration of a prism, showing the same in section A B C. A is called the *summit* or *apex*. B C is the *base*.

4. Refraction by a Prism. Let us consider Fig. 2, where the prism is shown in section. A ray of light from point D strikes the side at E, and we know from section 2 that when it passes into the glass from the external air it is refracted towards the perpendicular (shown by dotted line through E). But when it reaches the opposite side of the prism and emerges into the air

it is refracted away from the perpendicular (shown by dotted line through F). This emergent ray travelling on would enter an observer's eye at G, and would actually appear as if it came from H. An object therefore at D, when seen through the prism, would appear at H. The angle formed by the lines H O and D O is called the *Angle of Deviation*, being about half the size of the angle at the apex of the prism.

This displacement of objects may be readily tested with glass prisms of any degree. Before passing on to the next chapter it is most important that the passage of a ray of light through a prism should be thoroughly understood.

It must be remembered that—

(A) Light is refracted passing from one medium to another of different density.

(B) No refraction takes place when a ray strikes the surface perpendicularly.

(C) Entering a denser medium rays are refracted towards the perpendicular, but away from it in a rarer medium.

(D) Rays passing through a prism are refracted towards its base.

CHAPTER II.

Lenses.

5.—Definition and Kinds. A lens is a symmetrical body composed of a transparent medium such as glass, and having the power of causing luminous rays which traverse it either to converge or diverge. The surfaces of a lens are either both curved, or one curved and the other flat, as shown in the illustration below. Lenses are divided into two classes—converging or *convex* (called also positive or plus, and denoted by the sign +), and diverging or *concave* (called also negative or minus, and denoted by the sign –). There are three kinds of each class.

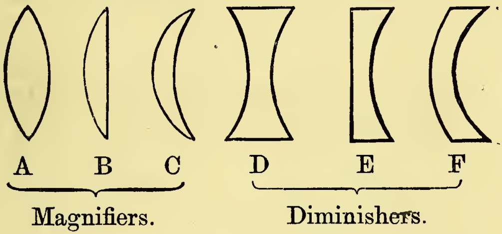


Fig. 3.

A. Double convex or biconvex.
B. Plano-convex.
C. Convex (or converging) meniscus or convex periscopic.
D. Double concave or biconcave.
E. Plano-concave.
F. Concave (or diverging) meniscus or concave periscopic.

We are now in a position, with the aid of section 3 and figure 2, to understand the refraction of luminous rays passing through a lens.

6. Refraction by Lenses. For our present purpose we may regard a convex lens of any kind as being composed of two prisms with their bases together, while a concave can be looked upon as two prisms with the summits or apices together. To form the proper curvature, the sides of the prism must be supposed bulged outwards for a convex lens and inwards for the concave.

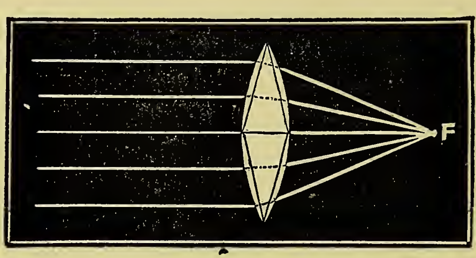


Fig. 4.

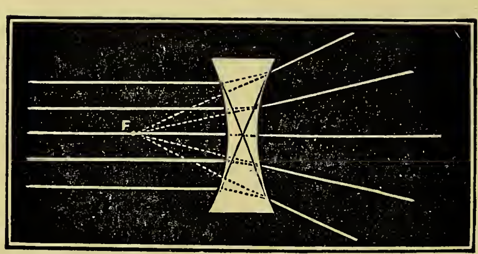


Fig. 5.

Passing through the upper part of a convex lens rays are refracted downwards, but in the lower part upwards, while the one through the centre undergoes no refraction, being perpendicular to the surface of the lens. In a concave the direction of refraction is reversed. The course of rays

passing through any lens may readily be remembered by noticing that they are always refracted towards the thickest part, this in a convex being the centre, in a concave the edges.

Transparent media vary somewhat in their refractive power, the denser the substance the greater being the refraction.

7. Refractive Index. Taking the refraction of air as approximately 1, we get the following values for various substances connected with optical apparatus:—

Diamond - - - - -	2·47 to 2·75
Crown Glass - - - - -	1·531 to 1·603
Flint Glass - - - - -	1·576 to 1·643
Canada Balsam (for cementing lenses)	1·540
Water - - - - - -	1·335
Aqueous Humour of Eye - -	1·337
Vitreous Humour of Eye - -	1·339
Crystalline Lens of Eye (outer coat) -	1·340
,, ,, (inner coat) -	1·379
,, ,, (central portion)	1·400

These numbers are known as the *refractive indices* of the particular substances enumerated, the values for glass varying somewhat with each separate maker. It is worthy of note that the diamond is much higher than any which follow.

From the fact that transparent media vary in their power of refraction, we can readily see that to get the same amount of bending in a ray of light, less curvature is required in a lens made from a highly refractive medium than in one of lower degree. A diamond lens, if it could be made, would be of less curvature than one of glass to get the same focal length. In much less degree this applies to pebble (rock crystal) and glass lenses; ground

on the same tool there would be a slight difference in focus, but unless the lenses are deep, that is of high power, the variation would be so slight as not to be of much importance.

8. Principal Focus. When the source of light is at a considerable distance from the lens, such as the sun, or even a gas flame at more than 6 yards away, we may assume that all rays proceeding from it are parallel when they meet the lens. These rays being refracted towards the thickest part, will meet in the case of a convex lens approximately at a point. The illustration below shows this at F, which is called the *Principal Focus* of the lens.

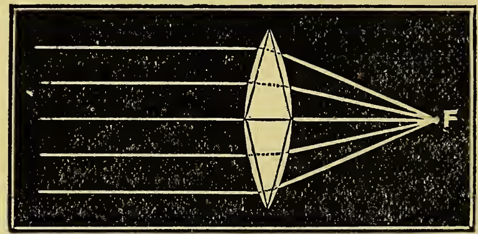


Fig. 6.

The distance from the centre of the lens to its principal focus is called the *focal length* or *focus.* The principal focus lies on a line which meets the lens perpendicularly and passes through its centre. This line is known as the *principal axis.*

In the case of a concave lens we notice that parallel rays are refracted in the opposite direction during their passage through, and will never meet as those of the convex do; still, by producing these lines backwards we find a point on the principal axis F (see Fig. 5), called the principal focus of a concave lens. This is what is known as a

virtual focus, whereas that formed by a convex lens is real. The distinction must be carefully noted. A real focus can be received on a screen placed on the opposite side of the lens, not so a virtual one.

The ordinary burning glass is an experimental proof of the fact that parallel rays passing through a convex lens all meet approximately at a point, rays of heat also being concentrated in a similar manner. We may reverse this and place the source of light at the principal focus of the lens, when all rays passing through will emerge parallel. This is utilized in the condenser of the Magic Lantern.

Convex glasses increase the number of rays entering an eye looking through them (as can be seen from the diagram), refraction bringing these closer together, while concave lenses diminish the number, refraction causing them to diverge after emergence. The principal focus of a double convex lens is practically in the same position as the centre of curvature of one of its faces, so that if we place the one leg of a compass on F (fig. 6), a circle could be described which would contain the one side of the lens as a part of its circumference.

9. Formation of an Image by a Double Convex Lens. In the preceding section it was shown that rays from the principal focus of a lens emerge parallel after passing through it, but if the point of light be moved a little further away from the lens, rays instead of emerging parallel will come to a focus on the opposite side and form an image there, and the further we take the light from one principal focus the nearer will its image approach the one on the opposite side, until when the light is practically at infinity (6 yards or more), the image falls on that principal focus. This is shown in the following diagram, where F and G are the two principal foci.

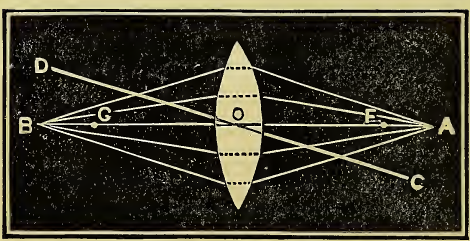


Fig. 7.

Placing a point of light at A we get an image formed at B, and the further A is moved from F the nearer does B approach G. We may reverse positions and put the light at B when the image is formed at A, and the further B is moved from G the nearer will A approach F. We learn from this that the positions of object and image are reversible, these points (A and B) being called *conjugate foci.*

Let us now move our light to C, a position which is on one side of the principal axis, and consequently not opposite the centre of the lens. A line drawn from C through the centre is called a *Secondary Axis,* and we can get an image of the light at C formed at a point D in much the same way as if it were on the principal axis. We might indefinitely multiply the points of light between A and C, and also on the other side of A, all having images on their own secondary axes, until we had a long bar of light made up of innumerable points forming an image of the bar made up of innumerable images of the separate points.

The accompanying illustration shows an object A C B and its image A′ C′ B′. Rays of light pass from every point of A C B, but we will confine our attention to those of the extremities A and B. Divergent rays from A pass

through the lens at all points (two are shown) and form an image at A′ on the secondary axis. An image of B likewise is formed at B′.

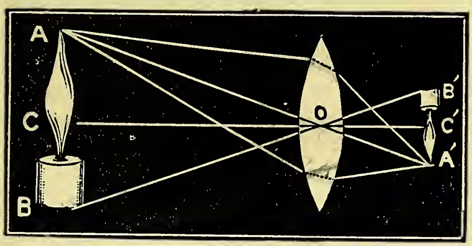


Fig. 8.

The intermediate points between A and B will fall between A′ and B′. This can be seen from the diagram, and we also notice the image is inverted. The above explains the inverted image on the ground glass screen of the photographic camera. The image is a real one.

When an object is placed between the principal focus and the lens itself, no definite real image is formed on the opposite side of the lens, but a virtual one can be seen on the same side. This is erect and enlarged.

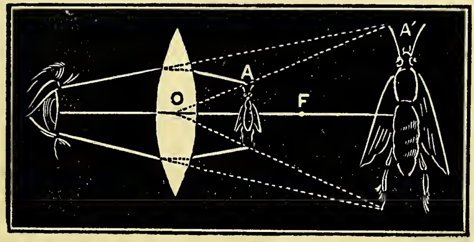


Fig. 9.

The illustration shows the eye placed so that the magnified virtual image can be seen. Rays from A are refracted by the lens, and entering the eye appear as if they came from A′, a point further from the lens than A. The opposite extremity of the object appears similarly further away as shown, and likewise all points between the extremities. This is the principle of the ordinary hand reading glass and various magnifiers.

10. Formation of an Image by a Double Concave Lens. Concave lenses give only virtual images at all distances. Rays proceeding from an object are refracted towards the thickest part of the lens, that is the edge

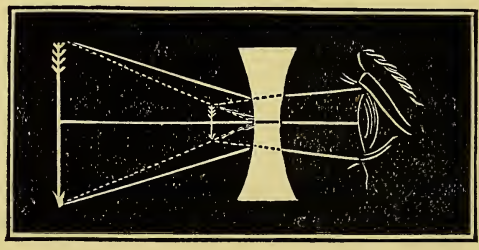


Fig. 10.

We see from the diagram that rays being bent outward appear as if they came from a much smaller object nearer to the lens. Fewer also enter the eye, so that the image appears dimmer than the real object.

11. Aberration. So far, in speaking of rays passing through a lens and coming to a focus, we have assumed that they all fall on the same point, as seen in the explanation of the principal focus of a lens. But such is not strictly true, as rays passing through the outer part of a convex lens actually come to a focus at a point nearer the

lens than those which pass through it near the centre. Hence we get a slightly blurred or confused image. This is called *spherical aberration.* We can, to some extent, remedy aberration by stopping the marginal rays and allowing the central ones to come to a focus. A focus can be obtained also by stopping the central ones and allowing the marginal rays to meet. The former proceeding is the one invariably resorted to, and much to be preferred. The diaphragms or circular discs of blackened metal with holes in the centre, which are used in many optical instruments, cut off superfluous rays which would otherwise cause aberration.

There are several devices by which aberration in lenses is much lessened, but we need only consider these with regard to scientific instruments, as aberration plays a very small part in lenses for correcting vision. Further details will therefore be given under Optical Apparatus.

Points to be remembered—

(A) In passing through a lens rays are refracted towards the thickest part.

(B) Parallel rays are brought to a focus by a convex lens at a point called the principal focus, and the distance from this point to the centre of the lens is called the focal length or focus of the lens.

(C) Conjugate foci are interchangeable positions of object and image.

(D) A real image can be received on a screen, but a virtual image can only be seen by looking through the lens.

(E) Concave glasses give virtual images only.

CHAPTER III.

Structure of the Eye.

12. The Eyeball. The eye is enclosed in a cavity of the skull called the *orbit,* in the posterior portion of which is a hole allowing for the passage of the *optic nerve.* By this the varied impressions of vision are conveyed to the brain. The eyeball is retained in position by the muscles which move it, by the optic nerve and the eyelids. It is padded in its cavity by masses of fat which provide a cushion for its every movement.

The size varies very little in different persons, but the eyelids being wider open in some than in others convey the impression of larger visual organs. The various parts of the eye are described below.

13. The Sclerotic or outer coat is a thick, white, almost horny covering which envelopes the eye, except for a circular space in front where it intimately joins a transparent membrane called the *cornea.* This much resembles a small convex watch glass. At the back the sclerotic admits the optic nerve, and is thicker here than elsewhere.

14. The Cornea is the clear transparent portion of the eyeball which we see when looking sideways at it. The appearance is so different from the sclerotic that we might scarcely believe them to be so intimately connected that the fibres of the one run into the other, being opaque in the sclerotic portion and transparent in the corneal part. The cornea is a part of the eye to which we shall have to give considerable attention when dealing with astigmatism.

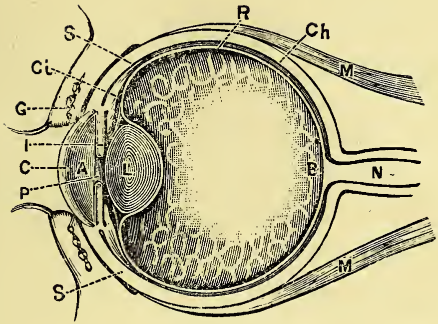


Fig. 11.

Longitudinal section of the eye from above downwards:—S, the Sclerotic Coat. C, the Cornea. L, Lens. A, Anterior Chamber. N, Optic Nerve. B, Optic Pore or entrance of nerve. Ch, Choroid Coat. R, Retina. P, Pupil. I, Iris. Ci, Ciliary Muscle. G, Glands. M, Muscles (superior and inferior).

15. The Crystalline Lens is a structure of great importance, lying about ⅙ of an inch behind the cornea in the normal eye, and dividing the eyeball into a small anterior chamber and a large posterior one. It is double convex and transparent, about ⅙ inch in thickness, having the posterior surface more curved than the anterior. Enclosing the lens is a transparent membrane called the *capsule,* which holds it in position, and is usually kept tightly stretched by a kind of membraneous framework the *suspensory ligament,* this being joined to the *choroid* coat of the posterior chamber by the *ciliary processes* of that coat. Thus the lens has a distinct connection with the choroid coat, a point we must remember.

The lens is not more than ⅓ inch in diameter, and is composed of layers almost like those in an onion. These increase in density inwards, as shown by the table on page

7, so that we should expect to find the central portion of greater refractive power than the outside. This is so.

16. The Anterior Chamber is filled by a watery fluid called the *aqueous humour*, and has a circular curtain, the *iris*, hanging in it immediately in front of the lens.

17. The Posterior Chamber encloses a glassy looking thicker liquid, which is much like the white of egg and called the *vitreous humour*.

18. The Iris is a coloured diaphragm, having in man a circular aperture, and hanging in the anterior chamber in front of the lens so as to adhere to its capsule. The iris gives what we call colour to the eyes, the *pupil* being the hole in its centre. This aperture in the cat tribe is a vertical slit, while it is horizontal in the ruminants. The size of the pupil may vary in a few seconds from $\frac{1}{8}$ to $\frac{1}{4}$ inch or *vice versâ*, these changes being effected by a series of minute muscles, some radiating and others circular, in the substance of the curtain itself. The iris is attached to the eyeball at the junction of the cornea and the sclerotic. At this point, too, is attached a series of small muscles all round the eye called the *ciliary muscle*, the use of which we shall consider hereafter.

The inner portion of the iris is laden with dark brown pigment or colour particles, absent in blue eyes, but particularly abundant in those of brownish hue, which have colour deposited not only in the inner part of the iris, but the front also. In Albinos, persons with pink eyes and white hair, there is an absence of colour here, as well as in other parts of the eye.

19. The Choroid is a membrane lining the posterior chamber of the eyeball immediately in front of the outer sclerotic coat. It is heavily laden with blackish brown pigment, and richly supplied with blood vessels, the dark

colouring matter preventing light from being reflected to sensitive parts of the retina near, which would cause the blurring and indistinctness of vision characteristic of Albinos.

In the sheep, cat, and some other animals, almost exactly opposite and a little above the pupil we find a patch on the choroid of satin-like whiteness called the tapetum, especially useful in reflecting a dim light to sensitive portions of the retina. This explains why such animals can see better at night than man, who has no such structure. The greenish hue sometimes seen in a cat's eye is due to the tapetum shining through the humours.

20. THE RETINA may be regarded as an expansion of the optic nerve, which enters the eyeball on the nasal side of the centre, and spreads out into this very delicate, almost transparent, membrane of a pinkish hue.

The retina is very little more than $\frac{1}{100}$ inch thick at its deepest portion, and although so very thin is one of the most complex structures. Under the minute ramifications of the optic nerve, which form the innermost portion of the retina, is found a closely packed mass of exceedingly small bodies known as the *rods and cones*. These lie side by side, and press against the choroid coat. Between them and the nerve layer there are other small bodies, but we may neglect such, merely mentioning them to show the complicated structure of the retina. The rods and cones do not exceed $\frac{1}{10,000}$ inch in thickness, and appear to be the actual structures which are sensitive to light, especially the cones, as we shall see presently.

Immediately opposite the centre of the lens there is a slight depression of a yellowish hue, known as the *macula lutea* or *yellow spot*. About $\frac{1}{10}$ of an inch to the inner or nasal side of this is a small patch having a radiating appearance,

called the *punctum caecum* or *blind spot.* Here the optic nerve enters the eyeball and spreads out. We shall have to consider these two areas in detail later on, suffice it to say that the cones are particularly numerous in the yellow spot, while there are neither rods nor cones in the blind spot, where all the nervous elements enter.

21. The Ciliary Muscles. In describing the attachment of the iris to the outer coat of the eye, mention was made that to the same part all round the eye the small fibres of the ciliary muscle were ultimately attached, the other ends being fixed to the under surface of the choroid coat. This muscle plays a very important part in vision.

22. The Lachrymal Glands. At the upper and outer parts of each eye glands are found, secreting a liquid whose function is to keep the cornea and other parts moist, thus preventing any accumulation of particles detrimental to vision.

A small red cushion, called the caruncle, may be seen in the inner corners of the eyes. Above and below this, close to each eyelid, is a small canal formed to drain off the lachrymal fluid as it is secreted. These two quickly unite forming a single tube, the *lachrymal duct,* which traversing the side of the nose for a short distance, passes through a hole in the bone and enters the nostrils. Tears are caused by a flow of fluid in such quantity that the duct cannot take it all away, consequently it overflows.

22a. Muscles of the Eyeball. Each eyeball is provided with six muscles by which it is moved in various ways, principally up and down and side to side.

These are—(1) *The superior rectus* or upper straight muscle (Fig. 11). (2) *The inferior rectus* or lower straight muscle (Fig. 11). (3) *The internal rectus* or inner straight muscle. (4) *The external rectus* or outer straight

muscle. All these four muscles are joined on to the sclerotic coat a little distance behind the cornea, and pass straight backwards to the aperture in the bony cavity which admits the optic nerve, where they are attached. When the superior rectus contracts (*i.e.* shortens) it helps to pull the eye upward, the inferior helping to pull it downward by its contraction. The internal rectus pulls the ball inward, and the external rectus outward. There are still two muscles to be mentioned—(5) The *superior oblique* and (6) The *inferior oblique.* These are attached to the eyeball behind its centre, and rather to the outer side. The inferior pulls towards the inner side, being attached to that part of the orbit; the superior also pulls towards the inner side, but passes through a peculiar loop and then runs directly backwards, being inserted on the same rim as the recti. The action of the oblique muscles is complicated, and need not be further noticed except to point out that they, to some extent, assist the superior and inferior recti in raising and lowering the eye, and also assist in oblique movements.

Points to be remembered—

(A) The eye is divided into two chambers with the lens between them.

(B) The lens varies in density, and consequently in refractive power.

(C) The lens is connected with the choroid coat, and is kept normally in a state of tension.

(D) The iris, a muscular curtain, is capable of varying the size of its aperture.

(E) The retina is a complicated structure with the Yellow spot and Blind spot at its hinder part.

(F) The ciliary muscle passes between the ends of the choroid coat and the sclerotic.

CHAPTER IV.

Vision.

23. The Dioptric Mechanism. This expression is used to define the arrangements by means of which an image is formed on the retina of the eye. In the first place it is important to notice that a sensation of light is very different from distinct vision. A slight pressure on the eyeball will cause a sensation of light, and we can tell the difference between day and night even with the eyelids closed.

To perceive objects it is absolutely necessary for an image of such to be formed on the retina of the eye, and the more sharply defined the image the more distinct is vision, so far as the dioptric mechanism is concerned.

The eye may be regarded as a camera, the iris acting as the diaphragm, the humours and the crystalline lens being the refractive apparatus, and the retina the screen upon which the images are thrown.

Rays of light passing from the outer surface of the cornea to the retina traverse in succession the cornea, aqueous humour, lens, and vitreous humour. The various surfaces of these are centred on an imaginary line called the *optic axis,* which meets the retina a little to the inner or nasal side of the yellow spot.

In chapter 1, section 2, we saw that refraction of light takes place at every surface bounding media of different density. Therefore, rays passing from air into the cornea

are refracted inwards (section 2). Next to the cornea the aqueous humour is entered, but this being practically of the same refractive power as the cornea no further refraction takes place till the lens is encountered. This, having a greater refractive index than the aqueous humour, causes further bending, especially as it increases in density towards the centre (see table in section 6). It will be noticed that the vitreous humour of the eye is very nearly of the same refractive power as the outer coat of the lens, so that little further refraction takes place.

We have here a combination of transparent media found to be wonderfully free from many defects which ordinary lenses possess, especially with regard to aberration, both spherical and chromatic; still, it must not be forgotten that the crystalline lens plays the greatest part in bringing rays to a focus.

Parallel rays of light falling on this combination are brought to a point about 22·5 millimetres (nearly 1 inch) behind the front of the cornea in the normal eye. Such is of course the principal focus of the combination, and the part of the retina intended to receive the image must occupy this position, and we find, moreover, that it is always one particular small area of the retina which receives the image when we get perfectly distinct vision. This, the *macula lutea* or *yellow spot*, described in section 20, must now further claim our attention.

24. YELLOW SPOT AND BLIND SPOT. We have so far traced a ray of light in its passage through the eye on to that portion of the retina specially adapted for the reception of images, the macula lutea or yellow spot. We may, indeed, still further limit the region, and say that for the most distinct vision images must fall on the central portion of the yellow spot, called on account of it being

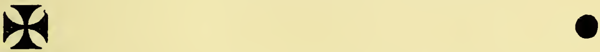
further depressed, the *fovea centralis.* Here the small bodies known as cones are particularly numerous, being densely packed side by side, with their ends turned inwards towards the lens. They are generally believed to be, as it were, receivers of the images formed on the retina, the recorded impressions being transmitted by the optic nerve to the brain.

We see, then, that only a very limited portion of the retina is used for distinct vision, and consequently only a small image can be received on this part. In viewing objects, the area we look at fixedly is really very small unless a great distance from us, and if we require to bring an adjacent portion into this field of greatest distinctness we move the eyes. Considering the minuteness of the image, we cannot but marvel how beautifully it must be defined on the macula for the normal eye to have such distinct vision. The further away from the yellow spot an image falls, the less distinct is vision, although every part of the retina is sensitive to light except one small patch, which, strange to say, lies only $\frac{1}{10}$ of an inch from the yellow spot. This is the *punctum caecum,* or blind spot, where, as we have already seen (section 20), the optic nerve enters the eye together with the blood vessels supplying various parts.

The spot itself is about 1·5 millimetres in diameter ($\frac{1}{16}$ inch), and although nerve fibres are so numerous there are neither rods nor cones. This fact, together with their great frequency in the yellow spot, goes a long way to prove that the cones are receivers of visual impressions. The presence of both macula lutea and punctum caecum can be readily demonstrated. Maxwell was the first to show that if a solution of chrome alum be held up between the eye and a white cloud a small rosy patch can be seen, which

however, soon disappears. The yellow spot absorbs some rays which the surrounding parts of the retina do not, consequently those remaining (the red) become visible over that area.

The existence of the blind spot can be still more easily proved. A cross and round mark are made on a sheet of white paper about 3 inches apart—



The left eye being closed we look intently at the cross with the right, and slowly move the paper to and from the eye. At a certain point the round mark will entirely disappear from vision, but moving the paper either backward or forward brings it into view again. The axis of vision passes from the cross to the fovea centralis when we look fixedly at the cross, and the image of the round mark falls on the inner side of this (see section 20). Moving the paper to and fro causes the image to recede and approach the yellow spot, and in so doing it crosses the punctum caecum or blind spot, becoming invisible as soon as it falls on that part. With a pencil we can actually draw an outline the exact shape of the blind spot, within which nothing will be visible. It is even possible in this way to denote the position of the principal vessels leaving it.

The existence of the blind spot is also shown by the fact that an image of light sufficiently small, thrown upon the optic nerve by means of the ophthalmoscope, gives rise to no sensations. How is it that there is no blank in our field of vision? "There are no visual organs in the blind spot, and consequently we are *in no way at all* affected by the rays of light which fall on it. There is in our subjective field of vision (the portion of our *brain* concerned in vision)

no gap corresponding to the gap in the retinal image. We refer the sensations coming from two points of the retina lying on opposite margins of the blind spot to two points lying close together, since we have no indication of the space which separates them."—(*Foster*). Moreover, in vision with two eyes the same image never falls on both spots, and although only $\frac{1}{10}$ inch away from the yellow spot the punctum caecum is outside the field of distinct vision. In the previous experiment we conclude there is a gap in vision, we do not see a black patch, to see black requires organs of vision, and these are absent in the blind spot.

25. Formation of Images on the Retina. If we refer to the section on the formation of images by a double convex lens, the diagram there will explain the formation of images on the retina. Considering A B as the object looked at, we should find a very small inverted image A′B′ upon the fovea centralis or central portion of the yellow spot.

As the image on the retina is inverted, how is it we do not see things upside down? A similar explanation is given to that in section 24 in the case of the blind spot. It is the brain which interprets retinal images, and the brain centres interpret the lower part of such images as being uppermost, other senses having combined to teach us this by experience. There is a decided advantage in inverted images, for with a given size of pupil we get a larger image on the retina on account of rays crossing when they pass through the lens.

26. Visual Angle—Idea of Distance. We have now to study a very important subject, bearing as it does on the use of Test Types. Below is a diagram showing three objects A B, A′B′, and A″ B″, equal in size but at different distances from the eye.

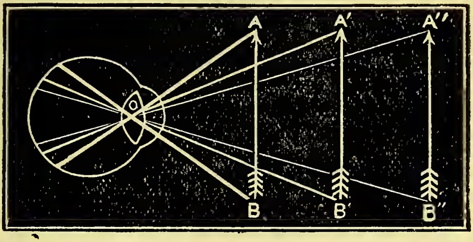


Fig. 12.

Tracing the paths of rays from their extremities to the retina through the refractive system of the normal eye, which has its centre (called the *nodal point*) near the posterior surface of the lens, we see that all three would form images of different sizes, although the objects are the same size, the greater the distance of the object the smaller being the image. The angle AOB formed by the lines A O and B O is called the *visual angle,* and the further we take the object away the smaller it becomes.

By a second diagram it can be shown that with the same visual angle objects very different in size form images of the same size.

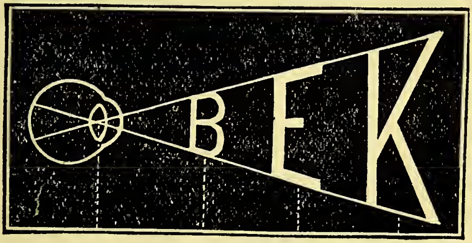


Fig. 13.

The letters above are at different distances and of

different sizes, but would all give images of the same size on the retina, so that the conclusions we arrive at from these two diagrams are,that we can neither judge the size of an object nor its distance from the eye by the size of the retinal image only. We judge of size by experience, comparing things of unknown dimensions with those whose size is familiar to us. The amount of accommodation (chapter VII.) necessary to focus the image is also an important factor, especially in determining the distance of the object. We further notice that in looking at a near object the axes of the two eyes converge, but in changing vision to more distant objects it is necessary for the axes to form smaller angles and converge less.

This is shown below, the axes of the eyes being in position for near vision, while the dotted lines represent them arranged for distant vision.

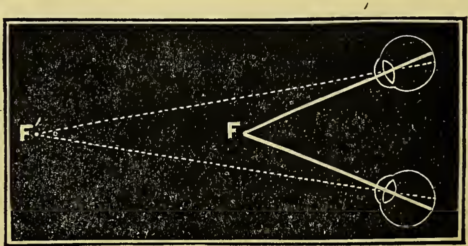


Fig. 14.

The *optic angle* is formed by the axes of the eyes and is greater for near vision than for distant objects. This is a factor in our estimation of distance; but custom and experience play the greater part, as shown by the fact that persons born blind, who have had their sight restored by operation, imagine for some time that all objects are at

the same distance. Movements of the eyes correspond, so that images fall on corresponding portions of the yellow spot, where this is not effected we get double vision or *diplopia.*

Points to be remembered—

(A) The optic axis is an imaginary line upon which the surfaces of all the media of the eye are centred.

(B) For distinct vision images must fall on the fovea centralis of the yellow spot.

(C) The blind spot or optic pore (entrance of the optic nerve) is quite insensible to light.

(D) The visual angle is formed by rays from the extremities of an object crossing at the nodal point.

(E) A small near object forms a larger visual angle and image than a large object a great distance away.

CHAPTER V.

Normal and Abnormal Forms of the Eye.

27. The Normal or Emmetropic Eye. This chapter, although short, is important, as it explains the causes of many defective eyes. Rays from a distance are approximately parallel when entering the eye, and if these come to a focus exactly on the retina without any effort on our part the eye is known as *normal* or *emmetropic*. Such an eye, of exactly the right length from lens to retina, is shown in diagram below.

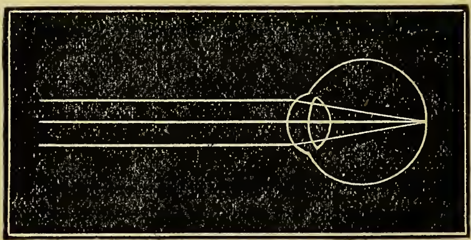


Fig. 15.

Although many people are not conscious of any defect of vision, strictly emmetropic eyes are rare.

All variations from the normal are known as *ametropic* eyes, such a term of course applying to every defect.

The emmetropic eye from front of cornea to the retina along the optic axis measures 22·824 millimetres.

28. The Hypermetropic Eye. This is the most frequently occurring defect, the eyeball being too short along the optic axis; it is generally considered to be due to an arrest of development, the eye not having grown to quite the right length.

It is frequently inherited from parents, several children in a family being affected.

The diagram below shows the course of parallel rays after entering the eye, the retina not being far enough back to receive the principal focus.

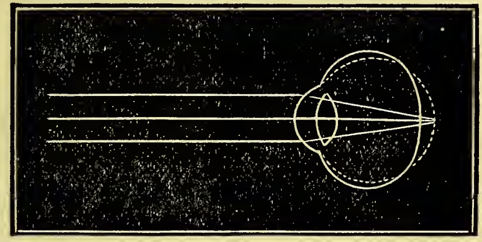


Fig. 16.

The defect produced by a hypermetropic eye is known as *hypermetropia*, and the person having it as a hypermetrope.

29. The Myopic Eye. The shape of the myopic eye errs in the opposite direction from the hypermetropic, being too long in the bulb. The consequence of this is that parallel rays entering the eye are brought to a focus at a point in the vitreous humour in front of the retina, as shown below.

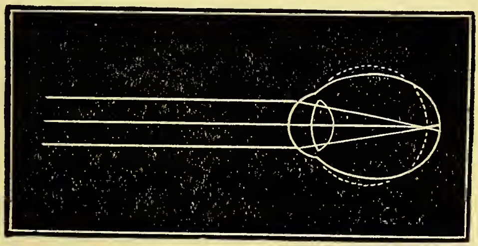


Fig. 17.

In these diagrams of hypermetropic and myopic eyes the dotted lines show where the retina should fall for them to be emmetropic. They are merely illustrations and much exaggerated.

Myopia may be hereditary, but there is no doubt that civilization and education intensify the defect, as will be seen when we treat the various defects separately. Persons suffering from myopia are called *myopes.*

The two defective forms described in this chapter are those chiefly found, and affect the whole bulb of the eye. We shall have to notice later defects which are caused by irregularities in the shape of the cornea.

We may summarize thus :—

(A) In the normal or emmetropic eye at rest the focus of parallel rays falls exactly on the retina.

(B) In the ametropic form known as the hypermetropic eye the focus falls *beyond* the retina and outside the eye.

(C) In the ametropic form known as the myopic eye the focus falls in the vitreous humour.

CHAPTER VI.

The Measurement of Lenses.

30. Systems of Measurement. Lenses for correcting such optical defects as we shall have to consider may be divided into *spherical, cylindrical,* and *sphero-cylindrical,* the last being a combination of the other two. Spherical lenses have surfaces equally curved in all directions, being sections of a sphere; whereas cylindrical surfaces are sections of a cylinder and are described later in Chapter XII.

Differing in many respects, both may be measured by the same systems, of which there are three in common use, although the dioptric is fast superseding the others.

31. The Fractional System. In this system a lens of 1 inch focus is taken as the standard, and being of very high power other lenses can be expressed as fractions of it. Thus a lens of 2 inch focus is written $\frac{1}{2}$, one of 8 inch $\frac{1}{8}$, one of 30 inch $\frac{1}{30}$, &c. It is now very rarely used, and is unsuitable for scientific work.

32. The Inch System was until quite recently the common method of numbering lenses, and still possesses such a hold that there are probably more marked in this system than the dioptric. Nearly all foreign spectacles and folders are ticketted in inches, but with advancing knowledge amongst opticians it is yielding to the dioptric system.

The method of reckoning is very simple, the focal length or focus being expressed in inches. Thus a convex lens which brought parallel rays to a focus at 18 inches distance is called $+18$ or $+18''$.

Concave sphericals are marked in inches too, but there is a supplementary system by which they are spoken of as Number 0, 1, 2, 3, &c. These numbers correspond (somewhat differently according to each maker's choice) to the inch system, and although utterly unscientific are much used in cheap work.

No. 0000	concave	= 48	inch.	No. 5	concave	= 14	inch.
„ 000	„	= 42	„	„ 6	„	= 12	„
„ 00	„	= 36	„	„ 7	„	= 10	„
„ 0	„	= 30	„	„ 8	„	= 9	„
„ 1	„	= 24	„	„ 9	„	= 8	„
„ 2	„	= 20	„	„ 10	„	= 7	„
„ 3	„	= 18	„	„ 11	„	= 6	„
„ 4	„	= 16	„	„ 12	„	= 5	„

It is sincerely to be hoped that this system of numbers as apart from inches for concave glasses will soon disappear, being totally useless and misleading.

33. THE DIOPTRIC SYSTEM. The most scientific and convenient measurement, and at the same time, one which is international, is founded on the metric system. The French *metre* is equivalent to 39·37 (nearly 40) English inches, and is divided into 10 *decimetres*, each of which is divided into 10 *centimetres*, these in turn being divided into 10 *millimetres*, so that there are 1,000 millimetres, or 100 centimetres in a metre. The metric system has many obvious advantages over the English system of yards, feet, and inches, and it is daily becoming a necessity for accurate measurements.

The dioptric system takes as its unit a lens of one metre focus called a *dioptre*, this in the inch system would be 39·37 inches, for convenience we will call it 40 inches. Thus we have a weak lens as our unit, and one of double the power would be two dioptres (written 2D). Just so a

lens of five times the power would be 5D. In the inch system a lens of 20 inches focus is twice the strength of a 40 inch, so that we can at any time convert the dioptres into inches by dividing 40 by the number of dioptres.

Thus 4D is a 10 inch lens ($\frac{40 \text{ inches}}{4} = 10$ inches). This explanation is given for the convenience of those who have only been accustomed to the inch system, but in future all lenses will be written in dioptres.

The intervals between the dioptres being too large, decimals are introduced to express intermediate lenses, ·25, ·50, and ·75 being used. The conversion to inches can be worked out exactly as before; thus a 2·75D lens is one of 14 inches focus ($\frac{40 \text{ inches}}{2{\cdot}75} = 14$ inches).

The dioptric system is a truly refractive one, enabling us to add and subtract lenses with an ease quite unknown in the others. Let us take an instance, adding together a lens of + 20 inches focus and one of + 30 inches focus. This involves considerable trouble unless we do it in the dioptric system. The + 20 inch is + 2D ($\frac{40 \text{ inches}}{20 \text{ inches}} = 2$) and likewise the + 30 inch is + 1·25D (approximately). Now by adding + 2D to + 1·25D we get + 3·25D. This is a + 12 inch lens ($\frac{40 \text{ inches}}{3{\cdot}25\text{D}} = 12$ inches). Just as we can add lenses so we can subtract them. + 5D can be reduced in power by taking away + 2D (for example) and we should have + 3D left. We may put it in another form and say that a + 5D lens side by side with a — 2D lens would refract (that is give the same focus) as a + 3D lens.

Cylinders are also numbered in the dioptric system, and, as we shall see later, can be added or subtracted just like sphericals, making allowance for the position of their axes.

The following table gives the equivalents in inches of all the dioptric numbers, reckoning 1 dioptre (the metre) as 40 inches, and calculating to the nearest inch.

Dioptres.	English inches.	Dioptres.	English inches.
·25	160	5·0	8
·50	80	5·50	7
·75	53	6·0	$6\frac{1}{2}$
1·0 The Standard	40	6·50	6
1·25	32	7·0	$5\frac{1}{2}$
1·5	26	8·0	5
1·75	22	8·50	$4\frac{3}{4}$
2·0	20	9·0	$4\frac{1}{2}$
2·25	18	9·50	$4\frac{1}{4}$
2·50	16	10·	4
2·75	14	10·50	$3\frac{3}{4}$
3·0	13	11	$3\frac{1}{2}$
3·25	12	12	$3\frac{1}{4}$
3·5	11	13	3
3·75	$10\frac{1}{2}$	14	$2\frac{3}{4}$
4·0	10	16	$2\frac{1}{2}$
4·25	$9\frac{1}{2}$	18	$2\frac{1}{4}$
4·5	9	20	2

If we take 39·37 inches as the dioptre we get minute fractions and several of the above figures would vary a trifle. This explains why some writers put 2·25 as 17 inches, the actual figure on that basis being nearer 17 than 18.

The French inch is now rarely used, 36 of these equalling the 1D, so that 36 French inches equal 40 English.

CHAPTER VII

ACCOMMODATION.

34. EXPLANATION. The eye cannot see distinctly far and near objects *at the same time.* Looking through a curtain at an object on the opposite side of the road we can see either the curtain or the object, but not *both* together distinctly. When we change vision from the far to the near object we are conscious of an effort in adjusting or *accommodating* the eye.

Below are diagrams illustrating the way in which rays from a distance (practically parallel), and those from a near object come to a focus.

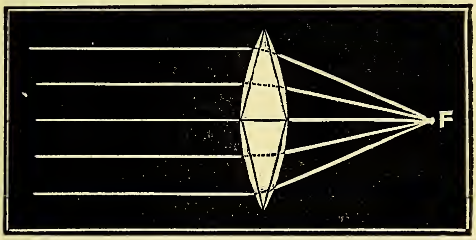


Fig. 18.

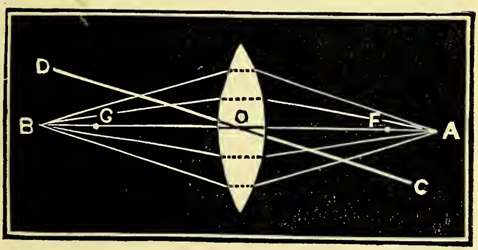


Fig. 19.

In the first instance rays meet at the principal focus, but in the second *beyond* this point. By what means could we bring that position nearer to the lens, so that the focus in the second case will fall on the same point as in the first? This is the problem presented by the eye's adjustment for near objects, as the retina is fixed and cannot be moved to and fro to receive images falling at different distances from the lens.

Rays proceeding from the object in the second illustration are much more divergent than in the first, where they are practically parallel. By putting a stronger lens in the second case we could adjust this, so that both images would fall at the same point.

35. Mechanism of Accommodation. The question arises—How is the adjustment of the eye for *near* vision brought about? The principal change is in the crystalline lens which becomes more convex, readily shown by an experiment due to Helmholtz. A lighted candle is held in front of the eye and a little to one side. An observer, looking into the eye from a position about the same on the other side of the eye, sees three images; one upright, formed by reflection from the front of the cornea; the second upright and larger from the front surface of the lens, and the third smaller and upside down from the back of the lens. When the eye is adjusted for near distance (accommodation) the second image becomes less and approaches the first, while the first and third remain unchanged. This shows that the front of the lens becomes more convex, and also that it approaches the cornea.

Evidently then, adjustment or accommodation of the eye is due to the lens becoming more convex.

The accompanying diagrams are merely illustrative of

the accommodative process, parts being enlarged and simplified to show the method more clearly.

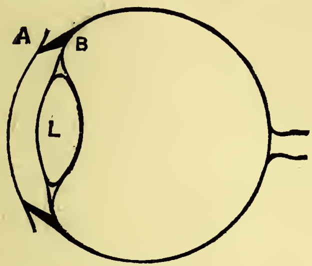


Fig. 20.

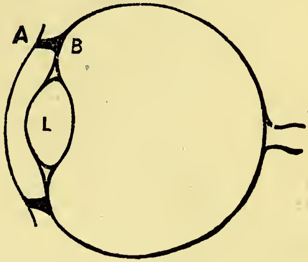


Fig. 21.

Figure 20 represents the eye at rest, just as we should find it when adapted for *distant* vision. Figure 21 shows the same parts after the change to *near* vision, that is after accommodation. L in both cases represents the lens with its capsule and suspensory ligament, the latter joining it to the choroid coat. A is the junction of cornea and sclerotic, and from A to B stretches the ciliary muscle, B being the part which joins the choroid.

These are all the parts concerned in the mechanism of accommodation, but we must remember that the capsule of the lens, when the eye is at rest, is always kept on the stretch by the suspensory ligament.

The effort felt when we accommodate for near objects is due to the contraction of the ciliary muscle. Now when a muscle contracts it brings its two ends closer together, thus B approaches A because the point A is a fixture, consequently B must move. Thus, all round the eye the edges of the choroid coat are pulled forward a little, and the suspensory ligament is slackened in consequence. By a peculiar arrangement of its fibres the lens is *highly elastic,* and immediately bulges out in its anterior portion

causing it to become more convex. This is exactly what we require to get an image of a near object focussed at the same distance from the lens as a far one.

The feeling of relaxation on looking at distant objects is due to the relaxing of the ciliary muscle, which allows the choroid fringe to fall back, and the lens capsule is pulled tight, causing the lens itself to become flatter.

Another feature of accommodation for near objects is the *contraction of the pupil*, which cuts off the outer rays of light. Dilation occurs when we look at distant objects; we then require more light to enter the eye.

36. THE FAR AND NEAR POINTS. The small ciliary muscle is of very great importance as we have already seen. When relaxed the lens has its least convexity, the eye is completely at rest, and is adapted for what is called its *far point* or *punctum remotum.*

The ciliary muscle contracting as much as possible causes the lens to assume its greatest convexity, and the eye is adapted for what is known as the *near point* or *punctum proximum.*

The far point, then, is the greatest distance at which an eye can see distinctly.

The near point is likewise the nearest point at which an eye can see distinctly.

The far point for the emmetropic or normal eye is *practically infinity* (6 metres or more).

The usual way in which the near point is determined is to find at what distance the eye can read No. 1 type (the smallest), of course trying each eye separately. There is, however, a simple method of accurate determination, known as *Scheiner's Test.*

Two small, smooth pinholes are made in a piece of card, not above $\frac{1}{8}$ inch apart (less than the diameter of the pupil).

This is placed close to the eye with the holes horizontal, while a needle or thin wire is held vertically at some distance away, being gradually moved up toward the card. At a certain point the needle (or wire) will appear double, and we have now reached the punctum proximum or near point for the eye tested.

Let us turn for a moment to the diagrams in Sections 28 and 29, referring to the hypermetropic and myopic eyes.

We know that the far point of the emmetropic eye is at infinity (6 metres or more), parallel rays being focussed on the retina when the crystalline lens has its least convexity, and the near point is generally about 20 centimetres (say 8 or 9 inches) when the lens has its greatest convexity.

But in the hypermetropic eye the rays focus too far back, the shape of the eyeball throwing the retina forward, therefore rays must be *convergent* (coming together) before they enter the eye to enable them to focus on the retina for the far point. This means that the far point is *beyond infinity*.

The shape of the myopic eye causes parallel rays to focus before they come to the retina, in this case rays must be *divergent* before they enter the eye, so that the focus may fall further back. Thus for the myopic eye the far point is *less than infinity*, that is less than 6 metres, while the near point comes so close as to be uncomfortable for distinct vision. The far point of myopes being so close we can frequently find it by Scheiner's test.

37. Range of Accommodation. This expression is used to denote the space between the far and near points, which will vary much in different cases.

Let us consider it in the emmetropic eye. The far point is at infinity, the near point about 20 centimetres away. To adjust the eye from one to the other requires greater convexity of the crystalline lens. Evidently the extra

convexity might be represented by a convex lens, which would be a measure of the force exerted to adapt the eye from its far to its near point. This force is called the *amplitude of accommodation.* A lens of the right power might be used in front of the normal eye to focus near objects at 20 centimetres instead of using the accommodation. If we find the near point (the nearest point at which small print can be read) *in an emmetropic eye,* and divide the distance into the metre (the standard), we shall get the lens which represents the force of accommodation necessary to bring vision from infinity (the far point) to the near point. Thus, in the case taken, where the near point is at 20 centimetres, we get $\frac{\text{100 centimetres (the metre)}}{\text{20 centimetres}} = 5\text{D}$.

We can also find this power by looking at *distant* objects through a concave glass, and gradually increasing the strength till we get the strongest with which we can see these objects distinctly.

The elasticity of the crystalline lens rapidly diminishes as we get older, commencing from about the tenth year; consequently the amplitude of accommodation decreases, the table below showing the amounts remaining at stated years.

Age of person.	Amplitude of Accommodation.
10 years	14 D
15 ,,	12 D
20 ,,	10 D
30 ,,	7 D
40 ,,	4·5 D
45 ,,	3·5 D
50 ,,	2.5 D
55 ,,	1·5 D
60 ,,	1 D
75 ,,	0

The following must be specially noted—

(A) Accommodation is adjustment of vision from far to near point.

(B) To effect this the lens becomes more convex on its anterior surface.

(C) The whole process is a muscular one, relaxation of the ciliary muscle for distance, contraction for near vision.

(D) The crystalline lens is highly elastic.

(E) In myopia the far point is less distant than infinity (that is less than 6 metres), in emmetropia at infinity (6 metres or more), and in hypermetropia it is beyond infinity.

(F) The amplitude of accommodation may be represented by a lens (found by dividing the near point into 100 centimetres).

CHAPTER VIII.

Test Types and Testing.

38. The Acuteness of Vision. So far we have been dealing with refraction, but now we come to a function of the *nervous arrangements* of the eye. There are cases in which we may fully correct refractive error, and still vision may not be acute. Although we cannot remedy such, we must understand in what respect they differ from ordinary acute vision.

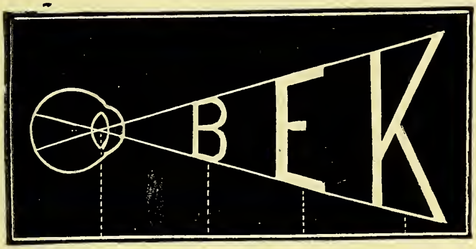
A circle is divided into 360 degrees (written 360°), each of these contains 60 minutes (written 60′), each minute 60 seconds (written 60″).

We saw in section 26 that when we look at an object, rays from the extremities would form an angle at the nodal point of the eye. We know also that objects of different size may subtend (or face) the same angle if placed at different distances. There must, then, be a limit to the smallness of this angle, and it is found that when two objects are so close together as to subtend an angle of *less than 1 minute* at the nodal point they cannot be distinguished as two, and are fused together.

It is very evident that we cannot have a correct comparison between the vision of two persons unless we have a standard, nor could we tell by how much we had improved a patient's vision without such.

There is now a general agreement to take a visual angle of *5 minutes as a standard*, and the normal eye should be able to see clearly any object which subtends that angle.

The diagram below shows an angle very much larger merely for clearness; but we see from it that letters between the lines bounding the angle vary in size according as they are nearer to or further away from the nodal point; still, all subtend the same angle, so long as they extend from one boundary line to another.



6 metres. 12 metres. 18 metres.

Fig. 22.

Let us suppose the above letters arranged at equal distances of 6 metres apart, B being also 6 metres from the eye, and so arranged as to subtend an angle of 5 minutes. They are called No. 6, No. 12, and No. 18 respectively, and if at 6 metres the eye focusses No. 6, at 12 metres No. 12, and at 18 metres No. 18, then vision is normal for that eye.

We should express vision as follows:—

$$\text{V (vision)} = \frac{6 \text{ (metres)}}{6 \text{ (No. 6 type)}} = 1, \text{ or shortly } V = \tfrac{6}{6} = 1.$$

But we may find a case in which No. 12 would have to be brought to 6 metres distance, showing that the visual angle is much larger than 5 minutes.

We should write vision—

$$V = \frac{6 \text{ (metres)}}{12 \text{ (No. 12 type)}} = \text{or } V = \tfrac{6}{12}.$$

We must not test vision for less than $\frac{3}{3}$, or accommodation will be exercised.

39. Test Types. Test types are formed on the basis of Fig. 22, letters composing them subtending an angle of 5 minutes, as we should naturally expect after reading the previous section.

Snellen's type is the best devised for testing, consisting of letters of various sizes with the distances marked at which they must be read by the normal eye. Thus 12 should be distinct at 12 metres, and 6 at 6 metres. Each separate letter is constructed so that the limbs are one-fifth the thickness of the whole, and the spaces between are either the same or multiples of it. The letter complete forms a square in such cases as E and M. This thickness of the limbs evidently would subtend an angle of one minute at the nodal point, which, as we have just learned, is the smallest angle for two points to appear distinct.

It is advisable to have two sets of type, as patients soon get accustomed to one set of letters.

For near vision many use Jaeger's type, the letters being of the ordinary printer's style and arranged in words, the different sizes are marked in centimetres for the distance at which they should be held from the eye, the letters then subtending an angle of 5 minutes at the nodal point.

Test types for astigmatism will be dealt with later on.

40. Testing. Before commencing to test, we must remember that for correct vision with both eyes two conditions are indispensable.

I. A distinct inverted image must be formed on the macula lutea or yellow spot of the retina of each eye.

II. The connection between the retina and the brain must be perfect.

With the second condition we are not concerned, that not

being the optician's business; but it is necessary to notice that there are two causes which might prevent a distinct image being formed on the retina. It may be merely the refractive apparatus of the eye needs correction, or, much more serious, some change of structure in parts of the eye itself, as in cataract. We have now to consider solely errors of refraction, and fortunately we have a very simple apparatus by means of which we can decide upon this point. The pin hole disc or round blackened diaphragm with a small hole in the centre can be fitted into a trial frame (a convenient cheap form with handle is made) and each eye tested separately, the pin hole being placed exactly opposite the centre of the pupil. A very small beam of light will pass through from the object looked at, and will traverse the axis of the eye, so that images of objects at all distances will be clearly defined (because only rays very near the axis are allowed to pass). If we get improved vision the refractive apparatus needs correction, but if there be no improvement the fault lies either in the transparency of the eye or the sensibility of the retina, and these we cannot consider. Much information with regard to the defect from which a patient suffers may be elicited by a few questions combined with observation. There is generally no lack of detail as to trouble, &c., which should be utilized as a guide.

The formation of the features is worth noting. It is almost unnecessary to call attention to the fact that various parts of the body frequently correspond in their general appearance; thus a person with long limbs will have an elongated body and head, and one with a short body will be short limbed. Just so the relation between the shape of the head and eyeball. Patients with a long face, deep from front to back of the head, and a prominent nose, suggest an eyeball too long, consequently we suspect myopia. The

face which has a flat appearance and less prominent nose than usual leads us to suspect that the eyeball is too short, causing hypermetropia.

In cases of high myopia the eyeball is visibly longer and appears to protrude from the eyelids.

Irregular faces suggest differences between the eyes, and frequently astigmatism.

Having noted these points, the test type for distance should be placed in such a position as to receive the light, while the patient should have his back to it, so as not to get the glare in his eyes.

Each eye must be examined separately, the other being covered by the black disc or ground glass.

Supposing that Snellen's No. 6 type is read at 6 metres distance, we may conclude that the eye is not myopic (short sighted), nor is it probable that astigmatism exists to any extent. It may therefore be emmetropic or hypermetropic.

Many young people will read No. 6 type at 7 or even 8 metres, in such a case we should describe the acuteness as $\frac{7}{6}$ or $\frac{8}{6}$; but where defects occur, we shall have to allow the patient to read large type, No. 12 perhaps; we then write $\frac{6}{12}$. Or, we may find that he can only see No. 36 (letters about 2 inches) at 3 metres distance. In this case vision is $\frac{3}{36}$.

Points to be noticed are—

(A) Two objects subtending an angle less than one minute at the nodal point appear as one.

(B) The standard of visual acuteness is an angle of five minutes at the nodal point.

(C) Test types are framed so that they shall subtend this angle at different distances from the nodal point of the eye.

(D) The pin hole test will show whether error of refraction, or change in retinal sensibility or humours.

(E) Facial characteristics are a preliminary guide in some cases.

CHAPTER IX.

Hypermetropia.

41. Symptoms and Causes. Hypermetropia is frequently called long sight, because eyes suffering from such can only see distant objects distinctly, and immediately reading, sewing, or fine work is commenced vision becomes indistinct, especially at night.

It is caused by the eye being too short in the bulb (section 28), so that the retina is too forward, and images formed by the lens would be behind it, where parallel rays are also focussed.

There are minor causes of hypermetropia, but the arrest of development referred to is undoubtedly the usual one. The diagram below shows the refraction of rays from distant objects; and yet the hypermetrope can see distant objects distinctly. How is this?

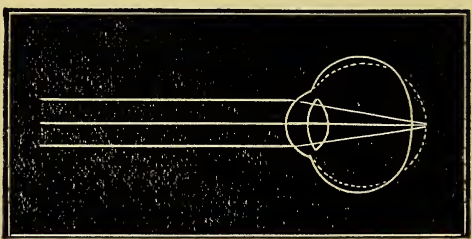


Fig. 23.

Accommodation should be used *only* for adapting the eye from distant to near vision. Referring to the diagram above we see that if the lens became more convex it would pull the image forward on to the retina; this is what the lens does in accommodation.

We see now the secret of the distinctness of distant vision in hypermetropes. They are *using their accommodation for distance,* whereas it should only be used for near vision, and having done so they have not enough left to focus objects close at hand.

How shall we remedy this state of things? Evidently by making the refractive apparatus convex enough to focus *distant* objects on the retina without having recourse to accommodation.

42. Testing and Treatment. Using the distant type (No. 6), we find the eye has $V = \frac{6}{6}$. This is obtained by the exercise of accommodation as shown above. We may relieve it by trying first a $+\cdot 50D$ spherical in front of the eye. Vision is just as good. We try $+1D$ with the same result, and so work upwards till we come to a lens with which the eye cannot see $\frac{6}{6}$. The lens below this is the highest with which $V = \frac{6}{6}$. Suppose it is $+3D$, evidently such is the measure of the hypermetropia, for it is the lens which will equal the accommodation previously used for distant vision. We must, however, qualify this statement and call $+3D$ the measure of the *manifest hypermetropia,* or that which is evident. There is, then, some hidden. Just so, and we call this portion *latent hypermetropia.*

In section 35 was shown how the crystalline lens is made more convex by contraction of the ciliary muscle. But a hypermetropic eye has been constantly doing it to focus distant objects, with the result that it is always in a state of tension or strain, called *spasm of the ciliary muscle.*

When we use the $+ 3D$ as above, the muscle will not relax to its full extent, and necessarily the lens still remains too convex. This extra convexity, which we cannot diminish except by using atropine, measures the *latent hypermetropia.*

Total hypermetropia, therefore, equals manifest hypermetropia (written H. m) + latent hypermetropia (written H. l). Using the drug atropine to the eye causes the ciliary muscle to relax to its uttermost, and we might find that our patient could see $\frac{6}{6}$ with + 5·50D. Evidently in this case there are 3 dioptres of manifest, and 2·5 dioptres of latent hypermetropia. It may be mentioned that as age advances the latent gradually becomes manifest hymetropia, so that even if we are accustomed to use atropine it is rarely necessary for patients over 30 years old, while in young persons we may get cases in which the hypermetropia is all (or nearly all) latent, then the weakest glass in front of the eye will interfere with vision.

How are those unused to atropine to correct the latent hypermetropia. Fortunately by adding about + 1D to the manifest we shall not err much. Even after using atropine it would not do to correct the whole of the latent, and usually only one-quarter of this is added to the manifest to get the total hypermetropia.

We must now consider the near vision of a hypermetropic eye. In section 37 is a table showing the total amount of accommodation remaining at various periods of life in the emmetropic eye; but in every case the hypermetrope will have as much less as is indicated by his total hypermetropia. Thus a child of 10 normally has 14 dioptres of accommodation. If he is hypermetropic to the extent of 6 dioptres he uses it to focus distant objects, consequently he has still 8 dioptres left for near vision This is ample, and his hypermetropia is no great inconvenience to him. But when that child becomes a man of 21, even if he had normal vision he would only have 10 dioptres of accommodation. Being hypermetropic he uses

6 dioptres to focus distant objects, and only has 4 dioptres left for near vision.

When he was 10 his near point was at $12\frac{1}{2}$ centimetres ($\frac{100 \text{ cm.}}{8D} = 12\frac{1}{2}$ cm.) about 5 inches, and as he could read much further away than that, evidently he still has accommodation to spare.

But when he becomes 21 his near point is at 25 centimetres ($\frac{1 \text{ metre or } 100 \text{ centimetres}}{4D} = 25$ cm.) or about 10 inches. He is now using the whole of his accommodation to read, a thing which frequently causes trouble.

We see from the above how necessary it is to correct any degree of hypermetropia except the lowest, because as age increases, or in case of illness, the balance of accommodation quickly runs down, and soon we get the marked symptoms of hypermetropia, near objects being indistinct, the near point rapidly receding.

Summarizing our proceedings.—

(A) We note that the commonest cause of hypermetropia is the eye being too short in the bulb, parallel rays focussing behind the retina.

(B) Therefore to see *distant* objects hypermetropes have to accommodate.

(C) To prevent this use + glasses in front of the eye till distant vision becomes indistinct.

(D) The highest power with which vision is distinct is a measure of the manifest hypermetropia.

(E) By using atropine we could continue and find the latent hypermetropia, caused by spasm of the ciliary muscle; but to get the total hypermetropia we must not add above $\frac{1}{4}$ of this to the manifest hypermetropia. Or,

(F) We can usually allow + 1 D for the latent and adding it to the manifest get the correcting power required.

CHAPTER X.

MYOPIA.

43. SYMPTOMS AND CAUSES. Myopia, or short sight, is in many respects the reverse of hypermetropia. The myopic eye cannot see distant objects distinctly, but focusses for near vision without any difficulty. The front of the eyeball often seems to protrude, and the eyelids are partially closed, as if too much light were entering the eye.

The chief cause of myopia is too great a length of the eyeball, images of objects being formed in the vitreous humour instead of on the retina.

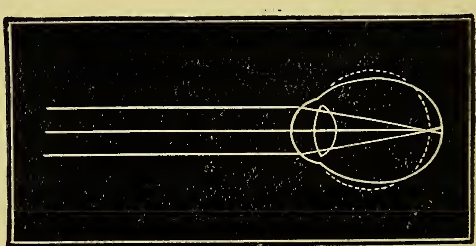


Fig. 24.

This extra length of eyeball is the result of high civilization, and the necessity of looking so much at very near objects. Myopia is not often found amongst country people and illiterates.

Given a myopic eye, then, what we have to do is to make the lens, in effect, less convex, that is, we must make parallel rays from a distant object divergent by using a concave lens in front of the cornea.

44. Testing and Treatment. We must, at the commencement, notice that accommodation is frequently unnecessary in myopia, for near objects are already focussed on the retina, and the far point is close to the near point.

In consequence of the little use made of accommodation, the ciliary muscle is frequently very small or wasted.

We must be careful not to give too strong a concave lens, as this would throw the image behind the retina, and the eye would exercise accommodation to bring it forward on to the retina, causing a strain on the disused muscle.

"The greatest distance at which an object can be clearly seen is the exact measure of the myopia; for instance, if the far point be at one metre, a concave glass of that strength (-1 D) would render parallel rays as divergent as if they came from a distance of one metre, and with a glass of this focus the person would be able to see distant objects distinctly"—(*Hartridge*).

Testing with the distant type we can also find the correcting glass, for it will be the *weakest* with which the patient can read $\frac{6}{6}$.

Again, we may try the eye with the reading type and perhaps find, that instead of reading No. 1 at 33 centimetres as marked, the patient brings it to within 20 centimetres of the eye, and cannot read further away.

Evidently ($\frac{100 \text{ centimetres}}{20 \text{ centimetres}} = -5\text{D}$) his myopia is 5 dioptres. Let us revert to the paragraph above from Hartridge and take a case in which the far point is at 50 centimetres instead of being at infinity as in the emmetropic eye.

Now 100 centimetres divided by 50 centimetres gives us —2D, which would make distant vision of the myopic eye the same as for an emmetropic eye, because it is just that power which will throw the far point back from 50 cm. to infinity.

In the previous case, where the punctum remotum or far point was at 1 metre, a glass of that power ($-1D$) would push the far point to infinity, thus making the eye emmetropic. Likewise with the far point at 2 metres, a glass of $-\cdot5D$ $\left(\frac{100 \text{ cm. or } 1 \text{ metre}}{200 \text{ cm. or } 2 \text{ metres}}=\frac{1}{2}=\cdot5D\right)$ would push the far point to infinity, and if it were 4 metres, a glass of $-\cdot25D$ would do it $\left(\frac{100 \text{ cm.}}{400 \text{ cm.}}=\frac{1}{4}=\cdot25\right)$; until, when we came to anything over 6 metres the glass would become so weak as to be almost without refractive power, consequently we should have a normal or emmetropic eye.

If the eye has, say, a far point of about $14\frac{1}{2}$ cm., we should conclude that a —7D lens would make it emmetropic, because it would push the far point back to infinity $\left(\frac{100 \text{ cm.}}{14\cdot5 \text{ cm.}}=7D\right)$. We should possibly find that such a person could see well with —6·5D or even —6D, showing that with the —7D the image is focussed *beyond* the retina and accommodation is used to bring it on to the retina. To prevent this it is advisable always to give the weakest lens, and so avoid over correction.

The power of accommodation remaining in myopic eyes can even be estimated. It is, evidently, the difference between the weakest and strongest lenses giving distinct vision.

We must in myopes always take into consideration the age of the patient and the degree of myopia. In young persons and low powers (— 2D, — 2·5D—3D) the ciliary muscle may be coaxed, as it were, into greater activity; so that such could read with their glasses, using their accommodation for near vision, as the lenses really make the eye emmetropic.

But in elderly people and cases of myopia of — 7D and upwards, accommodation will not take place in consequence of loss of power by the ciliary muscle, so that although the

eye is corrected for distance, they must not use these glasses for *very close work.*

45. TREATMENT OF HIGH MYOPIA FOR READING, &c. Suppose we have an eye with 8 dioptres of myopia, evidently the *far point* will be at 12·5 centimetres away ($\frac{100\text{ cm}}{8} = 12·5$). But this is much too close to be useful (only 5 inches). We want to remove the far point to say 33 centimetres. To give parallel rays (from infinity) the same divergence as from 33 cm. will require a glass — 3D ($\frac{100\text{ cm.}}{33\text{ cm.}} = 3\text{D}$). But at 12·5 cm. a glass of — 8D was wanted. If, then, we take — 3D from — 8D we shall have the lens required for reading, &c., but a caution must be given that work must not be brought nearer than 33 cm. (about 13 inches).

In all cases it is important that we should find the far point, and if this come much within the usual distances for near vision we must provide a remedy so that the limit is not passed.

Summarizing our proceedings—

(A) We note that the commonest cause of myopia is the eye being too long in the bulb, consequently parallel rays are focussed in front of the retina.

(B) Accommodation frequently is little used by myopes, the ciliary muscle becoming small or wasted from disuse.

(C) Great care must be taken not to over-correct, the weakest lens giving distinct vision being used.

(D) Testing with the distant type we find the far point. This distance is the degree of myopia, by calculating thus $\frac{100\text{ c.m. (or 1 metre).}}{\text{Distance of p. r.}} =$ degree of myopia in dioptres.

(E.) In young persons and low myopia the ciliary muscle can be coaxed into greater activity.

(F) In high myopia care must be taken that strain is not put upon the eye for near work.

CHAPTER XI.

PRESBYOPIA.

46. SYMPTOMS AND CAUSES. We only look for presbyopia in persons over 35 or 40 years who experience a difficulty in seeing small objects distinctly, holding a book or paper further from the eye, or endeavouring to find a better light. Larger type is sought, and a feeling of heaviness at night oppresses the eyes, especially after close work. The cause of presbyopia must be carefully remembered. We saw that hypermetropia and myopia were caused primarily by differences in the shape of the eyeball, existing from early years; but presbyopia is due to changes *in the dioptric mechanism caused by age.* As age advances the visual acuteness diminishes, and the *accommodation gradually lessens,* the lens losing its elasticity, and consequently it will not become so convex as formerly.

The ciliary muscle, also, loses part of its power of contraction. This loss of accommodation, as shown in the table on page 42, commences at the tenth year, when the body is only developing.

So soon as this loss of accommodation causes the near point of distinct vision to recede beyond the distance that a person usually reads ordinary print, then presbyopia has set in, and increased at the rate of about + 1 D every 5 years.

This point is now generally recognized as 22 cm. from the eye, and the emmetrope or person with normal vision will need lenses when about 40 or 45 years old.

We can easily see why this is so. Referring again to the table in section 37, we find that at 40 the emmetropic eye

has + 4·5 dioptres of accommodation left. But to bring vision from infinity to the near-point at 22 cm. will require 4·5 D because $\frac{100 \text{ c m.}}{22 \text{ c m.}} = 4{\cdot}5$. Consequently the eye uses the whole of its accommodation, and immediately the accommodation lessens, the near point recedes from its usual position.

47. Testing and Treatment. We shall now have to consider presbyopia in connection with the emmetropic, hypermetropic and myopic eyes, remembering that in all cases our object must be to supply by spectacles exactly that amount of accommodation lost inside the eye by failure of the dioptric mechanism.

In emmetropes who require the near point at 22 cm. we know that 4·5 dioptres of accommodation are absolutely necessary ($\frac{100 \text{ cm.}}{22 \text{ cm.}} = 4{\cdot}5$). But at 50 the amount actually remaining is only 2·5 D (section 37), therefore + 2 D lenses will be required to bring it up to what is needed. At 60 only 1 D of available accommodation remains, so that + 3·5D will correct, and at 75, when the whole of the natural accommodation is exhausted + 4·5 will be needed. It will be noticed that reading would not necessitate bringing the book to 22 cm. from the eye. This would be too great a strain on the accommodative mechanism. As we have seen the full accommodation cannot be used for sustained periods.

The table below gives the glasses required (approximately) at various periods of life to bring back the near point of emmetropes to 22 centimetres.

Age.	Accom. remaining at that age (Section 37).	Near point has receded to	To bring this back to 22 cm. requires
45	3·5D	28 cm.	+ 1D
50	2·5D	40 cm.	+ 2D
55	1·5D	67 cm.	+ 3D
60	·5D	200 cm.	+ 4D
70	0	infinity	+ 4·5D

From these figures it is apparent why every few years presbyopic patients come for stronger glasses, and every five years we shall be pretty safe in advancing + 1D to correct the natural failing of accommodation. The above remarks apply to normal or emmetropic eyes which become presbyopic. Separate consideration is necessary for hypermetropic and myopic eyes becoming presbyopic.

The hypermetrope requires a certain lens to correct a deficiency in shape of the eyeball, as we saw in Chapter IX., so that becoming presbyopic at a later date, a further correction will be necessary for this failing. Hypermetropes become presbyopic at an earlier age than emmetropes. In an emmetropic eye of 30 the accommodation remaining is + 7D. To focus objects at a near point of 22 centimetres costs that organ + 4·5 dioptres ($\frac{100 \text{ cm.}}{22 \text{ cm.}} = 4{\cdot}5$) so that there are 2·5 dioptres to spare.

Now if the same eye had been hypermetropic to the extent of 1 dioptre, this would mean that + 1 dioptre of accommodation would have been used up in focussing *distant objects*, and to focus near objects it would have that much less to spare than the emmetropic eye. But the latter had 2·5 dioptres in hand, so that this hypermetropic eye of 30 years has only 1·5 dioptres of its accommodation left after focussing near objects, and consequently will soon be presbyopic, for we saw that we must always allow some accommodation to remain in reserve.

It is very evident that when a hypermetrope becomes presbyopic we must add the correction for hypermetropia to what we should give an emmetropic eye of the same age, and prescribe a glass equal to both. Thus we first make the hypermetrope emmetropic, and then prescribe for his presbyopia as if he were really emmetropic.

Thus, if a patient of 50 has hypermetropia of +2·5D,

knowing that an emmetrope of 50 would be presbyopic to the extent of 2·5 dioptres (section 37), we should add these together and give a + 5D glass.

Arguing in exactly the same way, we can prescribe for myopes who become presbyopic; but everything will be reversed, and we shall have to subtract the correction for presbyopia (in an emmetropic eye of the same age) from the amount of the myopic defect, thus giving a weaker glass.

Let us consider an eye myopic to the extent of —4·5 dioptres, evidently such will have a near point at 22 centimetres ($\frac{100\text{ cm.}}{4\cdot5} = 22$ cm.) and needs no accommodation, so that even if this completely disappears it will make no difference.

This eye can never become presbyopic, and much more impossible will this be in myopia of higher power.

In cases of less than − 4·5D myopes will become presbyopic *later* in life than if they were emmetropic, instead of *earlier* as in hypermetropia. Thus, the amount of hypermetropia is a measure of the disadvantage to the hypermetrope becoming presbyopic, just as the amount of myopia is a measure of the advantage to the myope becoming presbyopic.

In the case of a person of 50 years, myopic to the extent of − 1·5D, we should note, that had he been emmetropic, at 50 he would require + 2 dioptres to bring near vision to 22 cm., so that the difference + ·5D represents the glass he requires.

Consideration of these points explains why some people never appear to get presbyopic to any extent. In earlier years they were myopic to an extent which did not cause serious inconvenience; but this, gradually counterbalancing the presbyopia as it increases with age, becomes an advantage to them.

We must bear in mind that the 22 cm. fixed by Donders as a near point would vary with the occupation and habit somewhat, just as some people read at nearer distances than others; so that those requiring a closer near point will require glasses a trifle stronger to correct their presbyopia, and for such as can do with the near point further away glasses a little weaker might be prescribed, the special requirements of each case deciding this.

Points to be noticed—

(A) Presbyopia is due to a decline in the power of accommodation, and becomes manifest usually at about 40 years of age.

(B) It commences when the near point of distinct vision recedes beyond the distance at which a patient usually reads, and increases at the rate of about + 1 D every 5 years.

(C) Our object must be to supply glasses to exactly counter-balance the accommodation lost.

(D) We take 22 centimetres as a standard for the near point in correcting presbyopia, so as to leave some accommodation in reserve, this being necessary.

(E) The hypermetropic and myopic eyes are corrected for presbyopia by making them emmetropic and then adding the amount for such presbyopia.

(F) Hypermetropes become presbyopic earlier, and myopes later in life than emmetropes.

CHAPTER XII.

Cylindrical Lenses.

48. Plano-Cylinders. Before commencing to study further defects of the eye it is necessary to examine the kind of lenses known as cylindrical, so called from their being segments of a cylinder, just as spherical lenses are segments of a sphere.

If we take a short round bar of wood and split it down the centre into two parts, this would be the exact shape of a convex plano-cylindrical lens. Pressing the rounded side into a cake of wax we should get a waxen shape of a concave plano-cylindrical lens. An ink line might be drawn down the centre of the rounded part of the wood, and similarly a mark could be made down the centre of the depression in the wax. The line on the wood is the *axis* of a convex cylinder, and the mark in the wax the *axis* of the concave cylinder. The examples taken would be lenses of very high power, but the illustrations on next page show lenses of less curvature, although still rather deep (10 or 12 D.) These are called plano-cylinders, as only one side is curved, the other being perfectly flat. Lines drawn from A to B in both cases would mark the axes, but usually small diamond scratches at each extremity indicate these.

If we pass the finger from side to side of a spherical lens in any position we are conscious of curvature of the surface, but not so with a cylinder.

Passing the finger from A to B (along the axis) we find

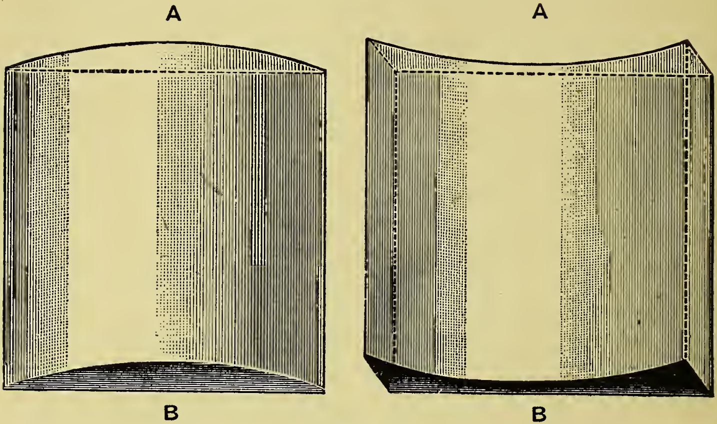


Fig. 25.

it is perfectly flat, but drawing it across at right angles we get the line of greatest curvature.

When we use a cylinder to look at objects, we shall find very important results follow from this difference in curvature. A square viewed through either a convex or a concave cylindrical lens appears as an oblong figure, the convex enlarging it one way, but not the other, and the concave diminishing it in one direction, but not the other. A little reflection will enable us to see the cause of this. Along the axes A B the lenses are flat, and consequently we should not expect the square to be altered in appearance in that direction; but *across* the axes (*i.e.* at right angles to them) the curvature of the lenses would show that the square would be enlarged in that direction by the convex and diminished by the concave. From this we learn that the greatest refraction by plano-cylindrical lenses always takes place along a line at *right angles to their axes.*

Plano-cylinders are marked like spherical lenses, in the dioptric and inch systems, convex and concave lenses of the same power neutralizing each other if held *with their axes together*. Another feature worthy of notice is, that two convex (or two concave) cylinders of the same power, if held with their axes at right angles to each other, will form a spherical *of the same power*. The oblong reading glass is usually formed of two convex cylinders ground in these positions. Thus a + 2D cyl. with axis vertical, put on a + 2D cyl. with axis horizontal, will form an ordinary + 2D spherical.

49. SPHERO-CYLINDERS. It has been previously mentioned that plano-cylinders have one side of the lens perfectly flat. We shall meet with cases requiring the use of this side for a spherical to be ground on it. If we take one of these and look at the square with it, supposing the spherical and cylindrical sides were both convex, we should find that the square would be enlarged in both directions but more in the direction *across* the axis of the cylinder than along it.

It must be remembered that—

(A) There is no curvature along the axis of a plano-cylinder and the greatest curvature along a line at right angles to the axis.

(B) A convex and a concave plano-cylinder of the same power, with their axes together, neutralize each other.

(C) Two convex (or two concave) plano-cylinders of the same power, with their axes at right angles, form a spherical of that power.

CHAPTER XIII.

Astigmatism.

50. Causes. Astigmatism is a defect quite different from any yet mentioned. Defects in shape of the eyeball account for most cases of hypermetropia and myopia, while presbyopia is a failing of the power of accommodation; but it is defects in the shape of the cornea chiefly which cause astigmatism, these usually being unchanged throughout life. Other causes scarcely come within the scope of this work.

In the astigmatic eye the cornea is of greater curvature across one part of its surface than another, and for all practical purposes we may place these positions as vertical and horizontal. This can be best illustrated by a diagram which represents the cornea of the eye as if it had been squeezed from above below.

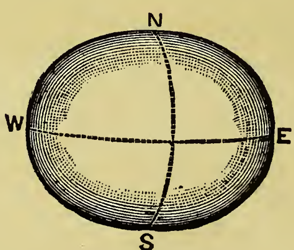


Fig 26.

It is very apparent, that if lines be drawn from N to S and E to W, the curvature along N S will be much greater than along E W. These lines are known as *meridians*, and could be placed at any angle across the

figure representing the cornea, but we must confine our attention particularly to the vertical (N S) and the horizontal (E W), for even in the normal or emmetropic eye *the vertical meridian is more convex than the horizontal,* but to only a slight extent, the diagram being much exaggerated.

A little consideration will show that rays passing through the cornea in the vertical meridian will come to a focus sooner than those which pass through the horizontal meridian. The following diagram is intended to illustrate this, rays from a point being focussed at different points according to the meridian they pass through.

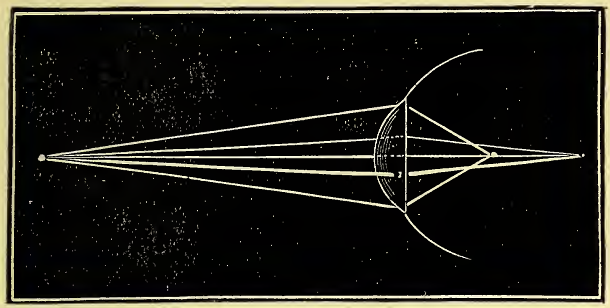


Fig. 27.

The central ray shown is of course in both the vertical and horizontal meridians, passing through the point of crossing in fig. 26, which may be of use to elucidate the above diagram.

The image of a point formed by an astigmatic eye is blurred, and not a point; as we see above, the meridian of greater curvature refracts more than the one of less curvature.

An interesting experiment is to take a paper with a cross formed of horizontal and vertical lines upon it, placing this

very near one eye and gradually moving it away. At a certain point the horizontal line becomes distinct while the vertical is still blurred, a little further distance being required to focus that. A little consideration will show us that it is the greater refraction (convexity) of the *vertical* meridian which focusses the *horizontal* line on the retina at a nearer point than the vertical line, so that the latter must be moved further away to be focussed by the lower refraction of the horizontal meridian. We note that for the horizontal line to be distinct the *sides or edges* of the line must be focussed, and these are vertical in relation to one another.

51. Varieties of Astigmatism. So far we have assumed that the vertical meridian is always more convex than the horizontal; sometimes we actually find the reverse of this, just as an egg usually lies on its side, but it is possible to stand some on end.

Furthermore, the meridians may not be strictly vertical and horizontal, but incline on one side or the other; they are, however, in all cases which we shall consider, at right angles to each other.

Every eye is astigmatic to a minute degree in many meridians, thus making a star appear radiate instead of round. This is known as *irregular* astigmatism, and is too small in degree to affect general vision.

There are five varieties to which we must give our attention—

(1) Simple hypermetropic astigmatism.
(2) Simple myopic astigmatism.
(3) Compound hypermetropic astigmatism.
(4) Compound myopic astigmatism.
(5) Mixed astigmatism.

The natural astigmatism of the emmetropic eye does not further concern us, as it is too slight to interfere with vision.

In simple astigmatism (hypermetropic or myopic) one meridian only refracts erroneously.

But both meridians have errors of refraction in compound cases (hypermetropic or myopic).

In mixed astigmatism one meridian is hypermetropic the other being myopic.

Especially notice that—

(A) Astigmatism is a defect in the shape of the cornea, one meridian being more convex than another. Irregularities in other parts of the eye may also cause it to a less extent.

(B) In the emmetropic eye the vertical meridian is more convex than the horizontal one.

(C) It is the rays from *horizontal* lines through the *vertical* meridian of the cornea which make these horizontal lines distinct.

CHAPTER XIV.

Testing of Astigmatic Cases.

52. Symptoms. Referring to section 51 it will be readily understood that the astigmatic eye will not see a point as such, but will get a blurred image on the retina. Especially is this the case with straight lines, some appearing more distinct than others according to their position.

When we test the patient for distance, vision is always below the normal, and generally neither convex nor concave glasses give any decided improvement. Looking at certain letters, the head is frequently held on one side, in which position they can be seen more distinctly, a certain sign that astigmatism exists. We should find in some cases that with one letter $V = \frac{6}{12}$ perhaps, while with another it might be $\frac{6}{9}$. It has previously been mentioned that an unsymmetrical face often gives us a suspicion of the existence of astigmatism.

53. *Testing.* The object in testing for astigmatism must be to find the meridians of greatest and least curvature. To do this special type and devices are necessary.

The type used takes the form of an astigmatic clock face, or a fan composed of radiating lines. The clock face is numbered from I. to XII., the opposite figures (such as III. and IX., I. and VII., &c.), being joined by three parallel straight lines, except for a small circle in the centre which is left white. This device should be placed about 6 metres from the eye, in a good light. We must be careful to test each eye separately, covering the other up with a disc.

The *stenopaic disc* is worthy of special notice, being exceedingly useful in readily determining the position of faulty meridians. It is a small circular sheet of metal the size of a trial lens, having a slit in the centre nearly an inch long and about $\frac{1}{12}$ inch wide.

The disc, when placed in front of the eye, will only allow rays to enter through that meridian indicated by the position of the slit, so that by turning it round we can find the positions in which the clock face is seen most distinctly, and also most indistinctly. These represent the meridians of least and greatest error, at right angles to each other. By having the disc on a small holder a patient can himself frequently find the meridian of least error almost immediately.

This is the special apparatus necessary, but there are various other devices more or less useful for determining the faulty meridians. Dr. Pray has constructed *test letters*, each being composed of parallel straight lines and arranged in a series from horizontal to vertical positions.

Looking at these, the astigmatic eye will pick that letter out as most distinct in which the direction of the lines indicates one of the chief meridians of the eye.

A variation of this is a series of circles similarly striped at different angles.

The disc of Placido is a sheet with a hole in its centre having concentric circles of black and white around it.

This can be used by placing the patient with his back to the light, and directing him to look at the centre, while the operator views the reflection of the concentric circles from the cornea through the hole in the disc. In astigmatic cases the circles will appear slightly elongated in the direction of the meridian of least curvature, but in low degrees it is only the practised eye which would notice the distortion; still it is a useful adjunct in testing.

Points to be remembered—

(A) Vision for distance is always below the normal in astigmatic cases, and frequently neither + or − glasses have improved it to any extent.

(B) We may feel tolerably certain of the existence of astigmatism if the head be held on one side to read certain letters.

(C) The object of all methods of testing for astigmatism is to find the meridians of greatest and least curvature.

CHAPTER XV.

Simple Astigmatism.

54. Simple Hypermetropic Astigmatism. In defects already considered we should find more cases of hypermetropia than of myopia, and just so we get more patients with hypermetropic than with myopic astigmatism.

When thinking of hypermetropia the idea of a convex lens being necessary to correct it at once comes into our mind,—we require greater *convexity.*

Exactly so in simple hypermetropic astigmatism, only that it will be one meridian of the cornea which requires greater convexity, the other (at right angles to it) being normal or emmetropic.

We learned in Chapter XIII. that in the emmetropic eye the horizontal meridian is generally less convex than the vertical, so that in a case of simple hypermetropic astigmatism, where one meridian has *insufficient convexity,* we should naturally expect that it would be the horizontal one.

We perhaps suspect a patient has astigmatism who sees test type badly, and $V = \frac{6}{18}$; so we put the clock face up, and find that he sees horizontal lines (IX o'clock to III o'clock) distinctly, but vertical lines (XII o'clock to VI o'clock) are blurred, the intermediate becoming blurred as they approach the vertical and distinct as they approach the horizontal.

But *horizontal* lines depend upon rays which pass from them through the *vertical* meridian for their distinctness, and *vice versâ,* so that when we find vertical lines indistinct we know the horizontal meridian is at fault.

Next, we place the stenopaic slit before the eye, and move it round until we find a position giving best vision with the test type, suppose the vertical. If $V = \frac{6}{6}$ with the slit so placed, and it is still as good when a +1D is placed in front, we may consider the vertical meridian emmetropic. So far no rays have passed through the horizontal meridian, which we suspect is faulty on account of the blurred vertical lines when first testing the eye; but now the slit must be placed horizontally, so that all rays entering the eye pass through that meridian of the cornea. Trying the test type, we get perhaps $V = \frac{6}{18}$ (No. 18 type at 6 metres); a weak convex lens *improves* vision, so we gradually increase the power until we find one giving $V = \frac{6}{6}$ (No. 6 type at 6 metres). This we will suppose is +1·5D, and looking at the clock face with it still fixed behind the slit, the patient sees all lines equally well.

The rays passing through a +1·5D spherical lens along a horizontal meridian correct this case; so that we must give a lens which will produce the same result. Rays passing through one meridian only are refracted exactly as a cylindrical lens of that power would refract them, its meridian of curvature being in the same position, but *its axis at right angles* (section 48). We can now dispense with the disc and spherical lens, and by placing a +1·5D cylinder in front of the eye with axis vertical shall correct the horizontal meridian and get $V = \frac{6}{6}$.

55. Simple Myopic Astigmatism. Just as myopia suggests that a concave lens is necessary to reduce the excessive convexity of the eye, so in simple myopic astigmatism we should expect to find the meridian of greater convexity in the emmetropic eye (vertical) still more convex.

For the same reasons as before we may suspect astigma-

tism in a patient, and perhaps cannot get better results with the test type than $V = \frac{6}{24}$, finding that the vertical lines of the clock are distinct, but the horizontal blurred. By rotating the stenopaic slit as before, the horizontal meridian is the one now giving distinct vision, and we get $V = \frac{6}{6}$ through it. If a + 1D does not interfere with vision we shall conclude that the horizontal meridian is emmetropic.

Turning the slit so that it is vertical we find $V = \frac{6}{24}$, and trying a + 1D in front it becomes worse, $V = \frac{6}{36}$ perhaps. Evidently a + spherical is not what is required. Putting a — 1D we get an improvement, and $V = \frac{6}{12}$; still increas ing the power, with perhaps a — 1·75D, we get $V = \frac{6}{6}$ and all lines on the clock equally distinct.

This means that a —1·75D spherical lens acting through the vertical meridian has corrected the defect, and reasoning as in the hypermetropic case, we should find a —1·75D cylinder with its axis *horizontal* would correct this simple myopic astigmatism.

Summarizing we find that—

(A) In simple hypermetropic astigmatism the meridian naturally inclined in the normal eye to be insufficiently convex (horizontal) will be still more faulty; while in simple myopic astigmatism the one inclined to be too convex (vertical) will be still more so.

(B) Testing with clock face, the eye cannot see both vertical and horizontal lines distinctly; we note the direction of the most distinct, and

(C) Rotate the slit to the position giving distinct vision, if a weak + lens makes no difference

(D) We move the slit to a position at right angles, find lines indistinct and vision with type bad.

(E) We try a + lens, if better, increase till $V = \frac{6}{6}$; but if

worse we try a —lens, which, if it improves vision, we increase till $V = \frac{6}{6}$.

(F) A plano-cylinder of the same power as the spherical, placed with its axis at right angles to the position of the slit, corrects these cases.

CHAPTER XVI.

Compound Astigmatism.

56. Compound Hypermetropic Astigmatism. In simple astigmatism we learned that one meridian of the cornea was faulty, while the other (at right angles to it) was emmetropic; but in compound astigmatism both are faulty, and *in unequal degrees.* For it is clear, that if both meridians were faulty (hypermetropic for example) to the same extent, there would be no astigmatism; whereas, in compound hypermetropic we perhaps find one meridian with + 2 dioptres of hypermetropia, while the other has + 3 dioptres or more.

The horizontal meridian is that which in the normal eye is of less curvature than the vertical (section 50), consequently when both are insufficiently convex we should expect the horizontal deficiency to be greater than the vertical, and this is generally so.

The procedure in testing for hypermetropic astigmatism is much the same in both simple and compound; but, trying the patient with test type, we should find vision worse in compound cases, perhaps $V = \frac{6}{60}$, and when the clock is looked at all lines appear blurred, the vertical especially so, showing at once that the horizontal meridian is the one principally affected. We therefore rotate the stenopaic slit to make sure of this, and commence testing the vertical, where the defect is least. Vision with the type is now perhaps $\frac{6}{12}$, and with the clock face horizontal lines are still hazy, while vertical will be better. As in

simpler cases we try + 1D spherical in front of the slit and find vision improved, possibly we get V $= \frac{6}{6}$, when this meridian would be corrected. There are cases where lenses of less power than + 1D (+ ·75D, + ·50D or + ·25D) would correct, but + 1D is taken in all these instances for the sake of uniformity.

Attention is now turned to the horizontal meridian, and looking through the slit in that position vision is very bad with the type. The vertical lines of the clock face appear to fade one into the other, but better results are obtained when + 1D spherical is placed in front. Continuing with + 1·25D, + 1·50D, &c., we perhaps with + 3D get all lines equally distinct, and V $= \frac{6}{6}$ when the type is used.

It is evident that + 1D has corrected the vertical, and + 3D the horizontal meridian; this being a case of compound hypermetropic astigmatism.

These results may be expressed graphically by putting a vertical line to represent the slit in the first case, with the correction near it, and a horizontal line for the second, thus:

(1) | + 1D   (2) ———— + 3D

These can be combined and a complete representation made by placing R (right) or L (left) in front:

+ 1D

R ——|—— + 3D

The question arises:—What lens is to be prescribed to

give this result? Evidently, + 1 D spherical will correct all the vertical defect and part of the horizontal, leaving + 2D of that meridian to be corrected. Referring to the section dealing with plano-cylinders we see that these glasses refract most along one meridian, but along the axis not at all. Consequently, if we arrange a cylinder + 2D with its *axis vertical* the meridian of refraction will correspond with this *horizontal* position which we want to correct.

Thus a + 1D spherical on one side of the glass and a + 2D cylinder, axis vertical, on the other side, corrects the above case of compound hypermetropic astigmatism.

By using atropine, accommodation is paralyzed, and the eye may be again tested, to ensure the best results; but this should not be used except in cases under 30, and unless the operator is skilled it is far better to gain experience without it.

In the eye suffering from compound hypermetropic astigmatism, rays refracted by the vertical meridian are brought to a focus behind the retina, while those passing through the horizontal meridian are focussed still further behind the retina.

57. COMPOUND MYOPIC ASTIGMATISM is the reverse of compound hypermetropic astigmatism, vertical and horizontal meridians being too convex, the former especially so, seeing it is the one with greater convexity in the emmetropic eye. To correct it we shall require a concave spherical combined with a concave cylinder.

We proceed exactly as in the last case, and find vision with the test type bad, perhaps $\frac{6}{36}$. The horizontal lines of the clock face are very indistinct, showing the vertical meridian to be especially faulty.

Trying the horizontal meridian $V = \frac{6}{18}$, and placing a weak convex lens in front of the slit vision is worse in every

respect, proving it to be the wrong lens, so that instead of proceeding with convex lenses we try a weak concave, and get $V = \frac{6}{9}$ with $-1D$. Increasing the power $-1·5D$ gives us $V = \frac{6}{6}$, thus correcting this meridian of its myopia.

Attention is next turned to the more defective vertical meridian, $V = \frac{6}{36}$, and horizontal lines are very hazy. The weak convex placed in front makes vision worse, so that concave lenses must be tried, with the result that as they are increased in power, V is successively equal to $\frac{6}{24}$, $\frac{6}{18}$, $\frac{6}{12}$, $\frac{6}{9}$, and perhaps $-4D$ gives $V = \frac{6}{6}$, all lines of the clock being distinct.

This may be written down as before, expressing the meridians and the power necessary to correct them—

−4D

R (or L) ——|—— −1·5D

In the above case −1·5D spherical will correct the horizontal meridian entirely, and −1·5 dioptres towards −4 of the vertical, leaving −2·5 dioptres of the vertical to be corrected.

We can effect this by — 2·5D cylinder with the axis placed horizontally.

Compound myopic astigmatism means that rays passing through the horizontal meridian of the cornea are focussed in front of the retina, while those through the vertical come to a point still further in front.

Summarizing our method, we—

(A) Note the eye sees some lines of clock face better than others, but none distinctly, and V is always bad.

(B) Place slit in position of least faulty meridian, and

(C) Test in that position; finding defective try a weak

convex, if it improves proceed with convex lenses till $V = \frac{6}{6}$; but if vision is worse try a weak concave and proceed till $V = \frac{6}{6}$.

(D) Put slit for opposite meridian and proceed as in (C)

(E) Combine the results of the two meridians and prescribe a sphero-cylinder.

CHAPTER XVII.

Mixed Astigmatism.

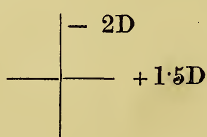
58. Cause and Treatment. In four typical cases of astigmatism we have seen that simple forms have one meridian emmetropic, while the other is either hypermetropic or myopic; but in compound forms both meridians are unequally hypermetropic or unequally myopic.

In the case which we are about to consider, the astigmatism is known as *mixed,* because while one meridian is myopic the other is hypermetropic. Thus, rays passing through the myopic meridian are brought to a focus in front of the retina, but rays through the hypermetropic meridian, at right angles to the other, will come to a point behind the retina.

The method of procedure will be the same as in the case of compound astigmatism, except that we may commence with either meridian, not knowing which is the weaker.

With the slit horizontal we perhaps find $V = \frac{6}{6}$ when $+ 1{\cdot}5D$ is in front; but on turning the slit vertically a weak convex makes vision worse, showing clearly that it is the wrong glass. We therefore try a weak concave, which improves matters; so that probably $-2D$ will give us $V = \frac{6}{6}$ for this meridian.

As we did in former cases, so now we may write our results graphically



The mode of expressing this in a sphero-cylindrical lens is rather more difficult. Proceeding as before we choose the weakest meridian as the basis for our spherical, this is $+1{\cdot}5$D. But we require a concave glass for the vertical meridian, so that we shall have to add $-1{\cdot}5$D (to neutralize the $+1{\cdot}5$D) to -2D for our cylinder thus getting $-3{\cdot}5$D. We must place this $-3{\cdot}5$D cylinder with its axis *horizontal* to correct the *vertical* meridian, as in this position it refracts rays passing through its own vertical meridian.

59. SUMMARY OF ASTIGMATIC TESTING. The preceding cases, with full details under separate headings, give one the idea that astigmatic testing is simpler than we really find it.

A patient requiring spectacles must be carefully examined to discover whether he is astigmatic, and once this is established beyond a doubt, we must find the position of the faulty meridian or meridians. As previously stated, in practically every instance these will be at right angles to each other, although cases do occur where this is not so, and where cylinders with their axes crossed at various angles are necessary for correction.

We must also notice that the position of the most faulty meridians may be quite contrary from the cases taken as illustrations, and in fact, may occur in any position. If one meridian is emmetropic, then we have only the other to correct; but when both are faulty we must determine whether both are hypermetropic, both myopic, or one hypermetropic and the other myopic.

A faulty *vertical* meridian of the cornea causes *horizontal* lines to appear blurred, and conversely a faulty *horizontal* meridian diffuses *vertical* lines. There is no refractive power along the *axis* of a plano-cylinder, but the *meridian* at right angles to this refracts to the fullest extent.

Two plano-cylinders (convex or concave) of the same power with their axes at right angles to each other make a spherical of that power.

When full correction has been made the spherical lens should be placed in the trial frame, and the plano-cylinder with its *axis* in the correct position in front of it, so that the patient may have an opportunity of trying the glasses.

CHAPTER XVIII.

Prescriptions.

60. Symmetry of the Eyes. Before commencing to describe prescription writing, one or two remarks are necessary as to the symmetry or otherwise of the two eyes.

Frequently they are symmetrical as regards defects of vision, but with careful testing many exceptions will be found, the different conformation of the two sides of a face being followed out to some extent even in the eyes. Especially do we find astigmatic patients varying, both as regards position of the faulty meridians and refractive error.

By far the most frequently erring meridians are the vertical and horizontal, as we have already seen. It is generally considered that an error of refraction in either of these positions interferes less with vision than when the meridian is oblique. Not infrequently one eye will to some extent correct the other, the defects only being fully experienced when using the eyes separately.

61. Prescription Writing. There are many details with regard to the writing out of prescriptions which must be understood; not only so that a successful correction may be written down in a scientific manner, but also that we may be able to comprehend what others have written.

The first point to be noticed is the method of indicating the two eyes. R E and L E are now generally used for right and left eyes, but some medical men use the symbols O D and O S, these being the initials of the Latin words for the same.

It is almost unnecessary to call attention to the need of

+ or – before lenses, and D after, to show that the measurement is in dioptres. There are still many who express lenses in inches, writing + 20″ for + 2D, + 12″ for 3·25, &c.

On page 86 is printed a prescription form in which there are spaces marked Sph., Cyl., Prs. for both eyes. With the Prism, as a glass for correcting vision, we are not concerned in an elementary work. In the Sph. division must be written the refractive power of the spherical lens, while under the heading Cyl. would appear the cylinder. Having done this we consult the printed "eyes" above in order to indicate the position for the axis of the cylinder. It will be noticed that the eyes are marked in degrees in the upper and lower portions in such a manner that the two ends of any line are numbered the same, commencing with 0° and running to 180°, thus forming a semicircle.

By drawing the pen through the line indicating the position of the axis of a cylinder all errors may be avoided, and it is much to be regretted that no fixed rule obtains in the method of marking the semicircles. Whereas some commence with 0° on the inner and upper side of each eye, and complete the semicircle with 180°, others begin on the outer side and mark inwards, while another will place 0° in the vertical position, marking down to 90° at the horizontal on each side of the eye. Even these do not exhaust the various methods, and in such a chaotic state it is necessary to be especially careful that no error arises from this source.

On page 86 the same prescription is written in three different ways, so that they may be compared. In I. we find the ordinary prescription form, only that the pen should be drawn through the degrees indicated. The spaces below are arranged for reading and distance prescriptions.

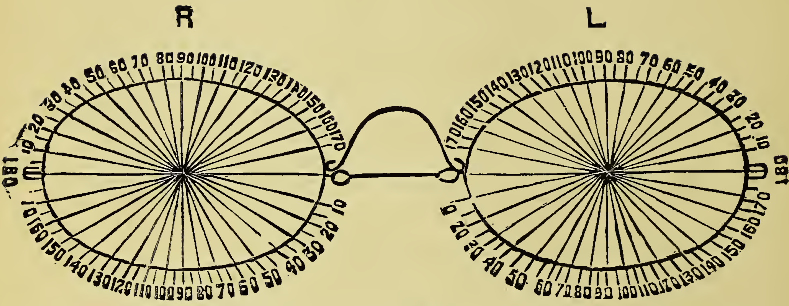
The style of No. II. is taken from the printed forms of a leading oculist. It will be noticed that 0° is in the same position for the L eye as in style No. I., but quite contrary in the R eye; consequently although the axis is the same the degree is *numbered* differently. The sign ⊃ means "combined with."

Style No. III. adopts the Latin initials, and does away with any form, describing the axis as "down and in" and "down and out," 0° being of course vertical.

In many infirmary and hospital notes the full working by which an oculist arrives at his conclusions is shown. Thus the expression R. V. $\frac{6}{24}$ H. m. 4D = $\frac{6}{6}$ indicates that vision of the R eye was $\frac{6}{24}$ without glasses. H.m. is manifest hypermetropia, and using + 4D spherical will give $\frac{6}{6}$.

By careful study of testing, and the methods of writing down results described in this chapter and in the articles on astigmatism, no case of puzzling complexity in writing need trouble anyone who is willing to spend a little time on it.

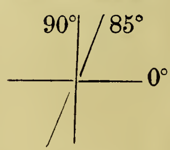
I.



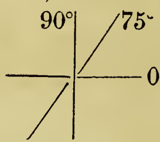
	SPH.	CYL.	PRS.	SPH.	CYL.	PRS.
Distance	+ 2·5D	+ 1·5D Axis 95°	—	+ 2D	+ 1·75D Axis 75°	—
Reading						

II.

R E + 2·5D Sph. ⊂⊃ + 1·5D Cyl. Axis 85°



L E + 2D Sph. ⊂⊃ + 1·75D Cyl. Axis 75°



III.

OD $\dfrac{+\,2\cdot5\text{D Sph.}}{+\,1\cdot5\text{D Cyl.}}$ Axis 5° down and in.

OS $\dfrac{+\,2\text{D Sph.}}{+\,1\cdot75\text{D Cyl.}}$ Axis 15° down and out.

CHAPTER XIX.

THE TRIAL CASE.

62. LENSES AND FRAMES. Trial Cases may be bought either with or without cylindrical lenses. For a complete outfit cylinders are necessary, but prisms are rather above the average optician, so that, if included, they are of little use to such.

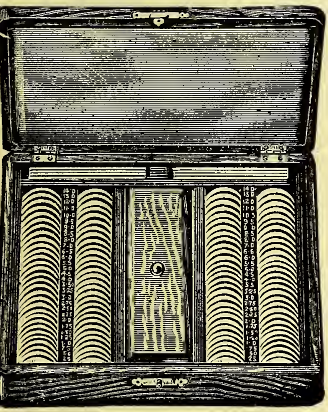


Fig. 28.

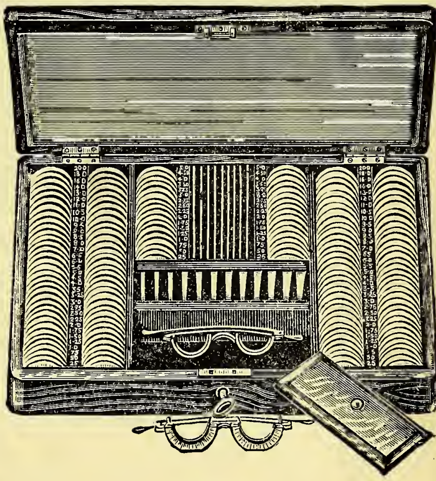


Fig. 29.

Fig. 28 shows a case containing sphericals with tinted slabs and a trial frame, the lenses running from ·25D to 20D in both convex and concave. Such can be purchased for under £3.

The illustration in Fig. 29 is of a full case of Sph. Cyls.

and prisms, with two trial frames (one double divided) and tinted slabs. A good case will cost about £1 more than the simpler one, prisms adding a further 15/- or so.

It is preferable to obtain an English made case, not so much because of error in the lenses of foreign cases, but because they very rarely contain the requisite powers necessary in actual work. A full set of glasses should include pairs of both convex and concave ·25D, ·50D, ·75D, 1D, 1·25D, 1·50D, 1·75D, 2D, 2·25D, 2·50D, 2·75D, 3D, 3·25D, 3·50D, 4D, 4·50D, 5D, 5·5D, 6D, 6·50D, 7D, 8D, 8·5D, 9D, 9·5D, 10D, 10·5D, 11D, 12D, 13D, 14D, 15D, 16D, 18D, 20D. In plano-cylindrical lenses it is only absolutely necessary to have a single glass of each power convex and concave from ·25D to 5D, the intermediate lenses as above. There should also be tinted plates and some small provision of discs.

In a spherical lens trial case one trial frame only is necessary, but that with cylinders will have two, the simpler one for sphericals, and a double divided frame with a semicircular plate marked in degrees for cylindrical lenses, one groove being used for sphericals and the second for cylinders.

63. Accessories. Under this heading may be included the various kinds of test type needed for practical testing, Snellen's for distance, and Jaeger's for near vision; the astigmatic clock and fan, supplemented by Dr. Pray's device, being useful for astigmatism. The pin hole disc with a small handle, and the stenopaic slit similarly mounted prove useful in addition to those usually found in a case, also a small frame with handle into which lenses may be readily placed.

A short rule marked one side millimetres and the other inches is frequently a convenience.

Many other devices may be obtained and added with increasing knowledge.

64. Use of the Trial Case. The chapters on testing show the necessity of an accurate trial case marked in dioptres; but the lenses may be used as gauges for finding the strength of unknown powers by neutralization. By this term is meant the combination of a convex and concave of the same power, the result being the absence of refraction, consequently objects viewed are neither magnified nor diminished by their union. Having a glass of unknown power we try against it those of the opposite kind, until we find one which completely neutralizes it; so that when they are held together in front of the eye and moved from side to side, looking at the bar of a window, we see no appearance of movement, the two glasses acting like a plane glass. Supposing the trial lens to be +2D sph., then the unknown glass is —2D sph. Tinted glasses need care in prescribing them. Smoke glasses are used to cut off some of the light—for diminution of *quantity*; but blue alter the *quality*, as they absorb the orange rays (see chapter 21, section 67), consequently these do not enter the eye.

CHAPTER XX.

Fitting of Frames

65. Necessity of Accurate Fitting. A line drawn through the nodal point of the lens to the fovea centralis of the yellow spot is known as the *visual axis.* It should be noted that this is not the same as the *optic axis* (section 23); still they are usually so close that the difference may be ignored for our present purpose, which is to show that the centre of the lens should be opposite the centre of the pupil in all such cases as we have considered.

Assuming that the centre of the lens is in the centre of the "eye" of a spectacle, we can easily see that the rim of such should surround the patient's eye symmetrically when the latter is viewed through it.

66. Size and Shape of Frames. To attain the above two things are necessary, and we must attend to (A) the centres of the eyes or *pupillary distance*, and (B) the fitting of the bridge. The centres of the eyes of frames may be measured in inches or millimetres, the latter giving smaller divisions. It is easier to measure from end of one eye to end of the other than from centre to centre, the most usual sizes being $2\frac{1}{8}$, $2\frac{1}{4}$, $2\frac{3}{8}$, $2\frac{1}{2}$ inches, the eyes usually increasing in size with the increase of pupillary distance.

The best bridge for fitting the nose is that known as the W, flattened as illustrated. If we imagine a line drawn through the centre of the lenses from joint to joint we have our starting point for the measurement of bridges. One, of which the centre of the flattened portion touches this line, would be described as *height* O, *projection* O.

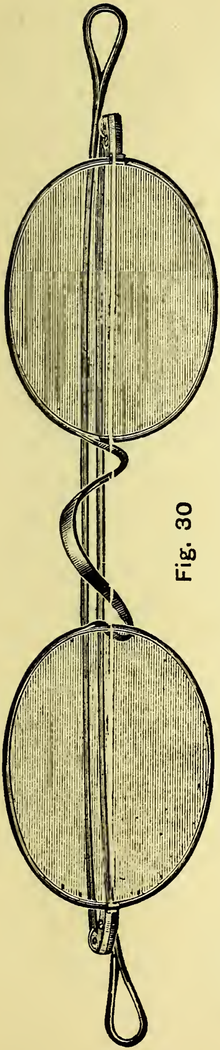


Fig. 30

If above the line in height, the number of millimetres or fractions of an inch can be expressed, and precisely so with its projection beyond the eyes.

Two measurements, then, are necessary, height and projection.

The space within the bridge needs consideration, as some noses are narrow and others broad.

Cases of slight nasal deformity are of frequent occurrence, when the bridge must be shaped to fit.

To prevent eyelashes touching the glass it is occasionally necessary for the bridge to *recede* instead of projecting, and some noses will require it to be placed *below* the central line.

The front of a spectacle or *facial width,* is measured from the end of one joint to the end of the other, and is usually about two inches more than the pupillary distance.

Some persons are narrow between the outer corner of the eye and the side of the face, requiring a short or *turn up* joint, while others are wide, and will take a long joint.

It is important to notice that frames for distance require to be a trifle higher on the face than for reading, and the latter are frequently better adapted by having *angled joints,* this arrangement tilting them forward a little.

Pantoscopic frames are angled, intended for reading, and allow the user to look at distant objects over the top.

There are numerous adjustable frames made for taking all measurements required; many are good, but few satisfactory in actual fitting, owing to patients having a dislike to such cumbersome apparatus on their faces.

The method employed by some of the most successful opticians is to have a series of frames of various bridges and centres (from 6 to 12 are sufficient). One frame gives the bridge and another the centres. They can be obtained fully numbered and lettered. By combining details of two frames the spectacle required may be obtained.

Periscopic spherical glasses will sometimes enable the eyelashes to move clear of the lens. They were suggested by Wollaston for giving a wider field of vision, but have the disadvantage of reflecting too much.

CHAPTER XXI.

Optical Apparatus.

67. Achromatism in Lenses. Achromatism means freedom from colour. To understand this we must refer to the prism (section 4). During the *refraction* of a ray of white light it is also split up into seven colours, forming a miniature rainbow, violet being refracted the most, indigo, blue, green, yellow, orange, and red following, the last-named being refracted the least. Such splitting up is known as *dispersion.* Passing through a convex lens each colour has a separate focus, violet being the shortest and red the longest, so that when we view an object through a strong convex glass we see rings of colour round it, the deeper the glass the greater being the colour.

Fig. 31.

Achromatic lenses are devised to obviate this, a most important matter in such apparatus as opera and field glasses, microscopes, and telescopes.

We have already seen that different kinds of glass have different refractive powers, so that by combining lenses (suitably ground) of *flint* and *crown* glass we can produce

a lens which re-combines the colours and gives clear definition. This would destroy the *dispersion* but not the *refraction*. The convex lens in Fig. 31 is crown, and the concave flint glass, both fashioned of such curvature as to reduce spherical aberration also (section 9). Lenses free from the latter are known as *aplanatic* and are specially useful in photographic cameras. A great advantage is gained in this respect by using two combinations a short distance apart, as it allows a larger aperture to be used than one only would.

68. Opera, Field, and Marine Glasses. These practically consist of two tubes, each having a *concave eyepiece* and a *convex objective*, arranged in such a manner that when vision is distinct the distance between the glasses is equal to the *difference in focus* between them, expressed in inches. Thus, a 2 inch concave eyepiece and a 7 inch convex objective would give distinct vision when 5 inches apart. Evidently there is a limit to the power which can be obtained with a given size of glass, the idea of very small glasses having very high powers being altogether fanciful. There are 4, 6, 8, and 12 lens glasses, these expressions referring to the combinations used to make them achromatic. 4 lens glasses are worthless; in 6 lens instruments the eyepieces are single, and objectives double (Fig 31), the two parts being cemented together with Canada Balsam. In 8 lens glasses the eyepieces are double in addition, while 12 lens have treble eyepieces (two concave and one convex part), and also treble objectives (two convex and one concave part). It is almost unnecessary to add that the greater the number of lenses the higher should be the degree of achromatism.

By examining the edges of the lenses a line can be discerned where the glasses are cemented together.

Few people are capable of judging the magnifying power of these instruments, and still fewer can compare one with another in this respect, especially in the higher powers.

Looking at an object through one tube only, with the other eye open and also viewing the object, we see a magnified image and the thing itself. By this means we can judge of the magnifying power, the freedom from colour rings round the edges of objects being a guide to their achromatism. To compare two glasses we look through a tube of each, and view the images side by side, a proceeding requiring a little practice. The usual magnifying powers are from 2 to 5 diameters, better glasses giving 8 and 10 diameters. A frequent source of trouble is the non-coincidence of the two fields of vision, due to the fact that the pupils of the eyes using the glass are not the same distance apart as the centres of the eyepieces. Glasses with bending bars remedy this, the tubes being movable can be adjusted to any pupillary distance. Opera glasses are merely smaller and of less power than field glasses, marine being shorter in form but of larger objectives, enabling a wider range of vision to be attained. This is a necessary feature of a sea glass, causing a slight sacrifice of power, but a gain in light (section 70).

69. TELESCOPES. In a telescope the objective, or glass nearest the object, is a convex achromatic combination of two or three lenses of comparatively low power, an image formed by these being magnified by a convex eyepiece. An astronomical telescope is essentially this, and images are formed upside down, a matter of indifference when viewing sun, moon, or stars; but for terrestrial work an arrangement of lenses is introduced between the eyepiece and objective, so that images may appear the right way up. Diaphragms are placed in the tubes to cut off the marginal

rays which would otherwise mar the definition. The size of a telescope is generally denoted by the diameter of its objective, the smaller being measured in lines (12 of which make 1 inch), and the larger in inches; thus we speak of a 16-line, a 19-line, or a 3-inch telescope.

The magnifying power may be tested in the same way as an opera glass. A good plan is to select an individual brick in a wall some distance away, and notice how many times larger its image is, by counting the number it covers as seen by the other eye. We then speak of it as magnifying so many "diameters" or "times," the former term being much more correct and less ambiguous.

70. The Microscope. In the microscope the objective is a small achromatic combination of lenses of very high power, so arranged that different "powers" can be screwed on, forming two and three in a combination, and giving different degrees of magnification. These are known as $\frac{1}{8}$in., $\frac{1}{4}$in., &c., "powers," the number denoting the focal lengths.

The principle of the microscope is as follows. The high power of the objective forms a real image much larger than the object, and the eye viewing this *real* image through the eyepiece sees a still larger *virtual* one. Usually the eyepiece is doubled, the two lenses being separated by an interval with a diaphragm between.

The magnifying power is referred to as 50, 100, 500, &c., "diameters," this being *linear* measurement, as in the case of telescopes, &c. We can also speak of 2,500, 10,000, &c., "times." These are the *squares* of the former numbers and denote *superficial* measurement. Thus a square magnified two diameters is four times its original area.

A *micrometer* is a small glass rule divided into $\frac{1}{100}$ths of an inch. By noting the size of one of these as compared with 1 inch outside, viewed by the other eye, we can find

the magnifying power. Thus, if the image of $\frac{1}{100}$ inch covers $\frac{1}{2}$ inch, the power is 50 diameters. In all instruments so far considered, with every gain in power there is a sacrifice of light.

71. THE MAGIC LANTERN is so well known as to need few remarks. The source of light has a mirror arranged at the back to reflect rays on to the *condenser*, two plano-convex lenses with their curved surfaces inwards, a rim of metal joining them together. The light should be at about the principal focus of the combination, so that emergent rays are parallel (in reality they are slightly divergent). These pass through the "slide" and meet an achromatic combination which throws an enlarged image on the screen, a screw allowing for focussing. The magnifying power at any distance can be calculated by dividing the space between screen and lens by the distance between lens and slide.

72. PEBBLES AND THE TOURMALINE. The substance known as pebble is a transparent mineral found in crystals, which vary in size. It is much harder than glass, and consequently not so liable to scratch, a matter of great importance when the usage of spectacles is considered. Pebble lenses absorb more heat too, consequently make the eye feel cooler.

There is a peculiarity in the refraction of light by a pebble lens which does not exist in glass, a single ray being split into two, undergoing what is known as *double refraction*. Most transparent minerals have this property, and objects appear double through them, but in the "pebble" of commerce one ray is absorbed, so that we see only one object. Nevertheless, pebble cut from the crystal exactly across its length absorbs the *extraordinary ray* more completely than that cut in any other position, and lenses ground from such slabs are known as *axis cut*.

Tourmaline is a semi-transparent mineral, which, cut into slices parallel to its axis, acts very peculiarly according to the position of the slabs. When lying parallel to one another light passes through both, but placed one across the other no light passes. On putting a pebble lens between them in this position light is transmitted, but glass will not cause this change. Here we have a ready test for pebble, but of much greater use is it for testing axis cut lenses. Looking at such through the tourmaline we get a series of concentric rainbow rings with a clear space in the centre, the whole having a black cross upon it in a certain position. Unless the rings are quite complete and central the pebble is not perfectly "axis cut." In taking slabs for axis cut pebble lenses the crystal generally cuts to waste, hence they are more expensive than the ordinary article.

The following list gives the prices at which many useful articles may be purchased :—

1. Snellen's Test Type, 4 different sheets, various letters and arrangements, paper, 21 inches by 9 inches ... ... 6d. per sheet
2. Jaeger's Test Type, folding cardboard, distances marked in centimetres, 11 inches by 14 inches... ... ... 9d. each.
3. Astigmatic Fan, paper, large size ... ... 9d. ,,
4. Astigmatic Clock Face, on cardboard, 23 inches by 20 inches ... ... 1/3 ,,
5. Test Type (after Dr. Pray), for astigmatism, 6d. ,,
6. Pin-hole Disc, black bronzed metal in nickelled steel frame and neat ebony handle ... 2/- ,,
7. Stenopaic Slit, in disc of bronzed metal with nickelled steel frame and neat ebony handle, 2/- ,,
8. Disc or Lens Holder, nickelled steel with neat ebony handle ... ... 1/6 ,,
9. Set of 6 **W** Bridge Frames (Fig. 30), for facial measurement, ticketted with full details of bridges and centres ... ...8/6 per set.
10. Ditto, of very finest workmanship 12/6 ,,
11. Set of 12 **W** Bridge Frames as above (No. 9), 16/- ,,
12. Ditto, of finest workmanship ... ...24/- ,,
13. Trial Case, with 140 spherical glasses, trial frame, and tinted plates as Fig. 28 ... 55/- each.
14. Trial Case, with 140 spherical and 36 cylindrical glasses, two trial frames, &c., as Fig. 29 (but no prisms) ... ... 78/- ,,
15. Folding Boxwood Metre Rule (folds into $5\frac{1}{4}$ inches), marked in millimetres, reverse side in English inches .. .. 1/- ,,
16. Two Sample Plano-cylinders, deep, + and —, 4d. ,,

Any of the above articles may be obtained from Messrs. J. & H. TAYLOR, *Manufacturing Opticians, 54, Tenby Street North, Birmingham.*

In all cases postage will be extra.